IMPROVING THE EXHAUST PIGMENT DYEING OF COTTON GARMENTS

S. HARILAL

2018

IMPROVING THE EXHAUST PIGMENT DYEING OF COTTON GARMENTS

By

Shantha Harilal

Submitted in fulfilment of the requirements for the degree of Master of Science in Textile Science to be awarded at the Nelson Mandela University

April 2018

Supervisor: Prof L Hunter

Co-Supervisor: Dr A Fassihi

NELSON MANDELA UNIVERSITY

DEPARTMENT OF ACADEMIC ADMINISTRATION
EXAMINATION SECTION
SUMMERSTARND NORTH CAMPUS
PO Box 77000
Nelson Mandela Metropolitan University
Port Elizabeth
6013

Enquiries: Postgraduate Examination Officer

DECLARATION BY CANDIDATE

NAME: **Shantha Harilal**

STUDENT NUMBER: **217071163**

QUALIFICATION: **Master of Science in Textile Science**

TITLE OF PROJECT: **Improving the Exhaust Pigment Dyeing of Cotton Garments**

DECLARATION:

In accordance with Rule G4.6.3, I hereby declare that the above-mentioned treatise/ dissertation/ thesis is my own work and that it has not previously been submitted for assessment to another University or for another qualification.

SIGNATURE: ______________________

DATE: **01 March 2018**

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude and appreciation to the following individuals and companies:

- Professor L. Hunter, my supervisor, and Dr A. Fassihi, my co-supervisor, for their invaluable guidance during this research study.
- Mr John Keith Hanson, Mr Albert Mesner and Mr Alan Judd for their dedication, continuous support, suggestions and literature.
- Mr Han Kuilderd and Mrs Patricia Reddy, of Spectrum Textiles (Pty) Ltd., for their collaboration, use of their dyes and chemicals, and facilities for conducting the dyeings trials.
- Mr Rabi Sukdeo of M & S Color Chem for the sponsorship of dyes and chemicals for this research.
- Gelvenor Consolidated Fabrics (Pty) Ltd, for the use of the spectrophotometer.
- The staff of the Department of Clothing and Textile Studies at the Durban University of Technology, for their continuous support.
- The Textile Technology students for assistance in the physical testing of the samples.
- The Clothing Management students for the make-up of the samples.
- My family and friends for their support and patience.

TABLE OF CONTENTS

Page

ABSTRACT

Due to the rapid changes in fashion trends, garment dyeing is gaining popularity because of its quick response time and reduced costs, especially when dyeing with pigments. However, a drawback of pigment dyeing of cotton garments is the problem of unlevel dyeing and poor wet fastness, together with the high amount of staining of the dyeing equipment.

This research has focused on investigating the effects of varying dyeing parameters on the colour strength and fastness of exhaust pigment dyed cotton garments, with the ultimate aim to improve colour strength, wet rub fastness and wash fastness; as well as try to reduce the amount of staining of the equipment, and in so doing reducing production and effluent treatment costs. The research was undertaken at a textile company, Spectrum Textiles (Pty) Ltd, which has been experiencing problems with poor wet fastness, unlevel dyeing and high staining of equipment for both knitted and woven cotton garments.

Trials on knitted and woven garments were carried out in which the effects of the concentrations of the cationising agent, pigment and binder/fixer, on colour strength and dye fastness were investigated, as was also the effects of temperature, pH, material-to-liquor ratio and process route.

The dyed fabrics were analysed in terms of colour strength, wash fastness and wet and dry rub fastness. It was found that, in general, increasing the amount of cationising agent, pigment, binder/fixer, pH, temperature and material-to-liquor ratio decreased the colour strength (K/S), with applying the binder/fixer prior to pigmenting mostly producing a higher K/S than when applying the binder/fixer after pigmenting. Furthermore, the use of a fixer achieved higher K/S values than when the binder was used. By the selection of the correct chemical levels and dyeing conditions, level pigment dyeing of cotton garments, with high colour strength, was achieved with Grey Scale ratings of 4 or higher for all the fastness criteria. A single optimum dyeing combination, which produced a high K/S and a Grey Scale rating of 4 or higher for wash fastness and wet and dry rub fastness, was derived.

Keywords: exhaust dyeing, cotton garments, pigments, cationisation, pH, temperature, binder/fixer, MLR.

LIST OF ABBREVIATIONS

AATCC:	American Association of Textile Chemists and Colorists
AGU:	Anhydroglucopyranose Units
ATS:	Advanced Textile Services Laboratory
BS:	British Standards
Cat:	Cationisation
C.I.:	Color Index
C.I.E.:	Commission Internationale de l'Eclairage
DP:	Degree of Polymerization
ELS:	Extra-long-staple
ISO:	International Standards Organization
LAV:	Large Area View
M & S:	Marks and Spencer
MLR:	Material-to-Liquor Ratio
OH:	Hydroxyl Groups
owf:	on weight of fabric
PFD:	Prepared for Dyeing
SANS:	South African National Standards
SDC:	Society of Dyers and Colourists
Temp:	Temperature

LIST OF FIGURES

LIST OF TABLES

Chapter 1: Introduction and Scope and Objective of Study

1.1. HISTORY AND OVERVIEW OF GARMENT DYEING

Garment dyeing has been practiced for decades, both commercially and as a home procedure. Interest in this technique has increased in recent years since it enables rapid response to changing consumer demands, and reduced lead time and inventory (Saha and Dina: 2015). Originally, only knitted garments, from natural fibres, such as underwear, sweaters, pullovers, socks, tights, pantihose and stockings, were dyed, but garment dyeing was extended to nylon and acrylic fibres from around 1950 onwards due to commercial availability. Nevertheless, the dyeing of cotton garments was largely limited to over-dyeing, carried out by laundries and dry-cleaners, to give such articles a new lease of life (Park and Shore: 2004).

Ever since the formation of major retail organisations, offering ranges of textile garments, there have been commission dyers specialised in processing fully-fashioned garments of the highest quality (Park and Shore: 2004). Woven fabric garments, in particular cotton, cotton/polyester and viscose garments for leisurewear (Christie *et al*: 2000); and casualwear goods varying greatly in colour and fashion details, have a large global market (Park and Shore: 2004). Design and fashion have become important features for this sector which has led to the need for quick response in manufacture (Christie *et al*: 2000), for which garment dyeing is ideally suited since it occurs very near the end of the manufacturing pipeline.

1.2. ADVANTAGES AND DISADVANTAGES OF GARMENT DYEING

As with any process, there are always advantages and disadvantages, Table 1.1 is a listing of typical advantages and disadvantages of garment dyeing.

Table 1.1 Advantages and Disadvantages of Garment Dyeing (Park and Shore: 2004, Christie *et al*: 2000).

Advantages	Disadvantages
1. The capability to produce small batches in a range of colours, which would be uneconomical by other processing routes.	1. The knitted garment may contain panels from different knitted batches, giving rise to bulk variations and difficulties of penetration and levelness.
2. The colour to be dyed can be delayed until the very end of the production sequence.	2. Inadequate yield, patchy dyeing and poor penetration of seams.
3. Reduction in coloured waste textile materials.	3. The possibility that the garment dyeing method can be eroded by other techniques on the basis of cost, ease of dyeing blends, better colour continuity and higher fastness.
4. Lead times can be reduced by $1/4^{th}$ or more.	4. Only solid shades can be dyed.
5. Many desirable effects, required in knitgoods, can only be obtained by garment dyeing and finishing.	5. There is a possibility of cross-staining if the garment contains more than one fibre type.

The third disadvantage (Table 1.1) has been overcome, as the importance of 'quick response' was realised, facilitating rapid changes in colour and fashion to meet current demands. The success of garment dyeing has been assured by developing processes and products not traditionally dyed in this form, in particular processes to simulate the fashionable 'distressed or worn look' associated with worn denims (Park and Shore: 2004).

1.3. PIGMENT DYEING OF GARMENTS

Cotton garments are dyed with Direct, Vat, Mordant, Sulphur and Reactive dyes. They are, however, predominantly dyed with reactive dyes, due to the wide range of bright colours, which produce excellent colour fastness to washing. The dye-fibre interaction is due to covalent bonding under alkaline conditions; which requires large quantities of inorganic salts, such as sodium chloride or sodium sulphate, and the inorganic alkali such as sodium bicarbonate, sodium carbonate or sodium hydroxide. These salts and alkali, drained into the effluent, generate heavy amounts of total dissolved solids, leading to environmental problems. Thus the need for alternative, more environmentally friendly dyeing methods, one of which being pigment dyeing.

The choice of pigments, over common dyestuffs for the dyeing of cotton, lies in the fact that pigment colourants tend to be highly durable, heat stable, solvent resistant, light and migration fast; and more environmentally friendly and can be applied to most substrates, including fibre blends, and require minimal effluent treatment. They tend to have poor colour brilliance and strength, however (Zhang: 2010). Dyes, on the other hand, provide brighter colours than pigments, but are less light stable. The difference between dyes and pigments is that dyes are soluble in the substrate and thus disperse at a molecular level, while pigments are insoluble and are dispersed as particles (Rothon: 2012).

The dyeing of garments, using pigments, is the simplest and most economical process, as it consists only of dyeing, drying and fixation; thereby eliminating all wet after-treatments and reducing processing costs (Miles: 2003, Aspland: 1997).

1.4. EXHAUST PIGMENT DYEING OF GARMENTS

Pigments are non-ionic in nature, and when dispersed in water will have no affinity towards anionic cellulose fibre in the dyebath. Therefore, the use of pigments, to colour textiles, was limited to pad application, due to their inability to exhaust onto fibres.

Patra *et al* (2006) stated that one of the first companies to apply pigments by the exhaust technique was an American company called Centigrade, with this technique only attracting attention until 1987, in Europe, when an Italian company introduced the system with a view to get ‘ready worn’, ‘washed down’ effects, similar to the stone wash effect on denims (Lever: 1992). Cotton Incorporated (2000) also confirmed that exhaust pigment dyeing of garments was developed to produce the ‘weathered’ or ‘distressed’ look.

The only technique suitable for the colouration of garments is that of the exhaust dyeing method, with the process route differing when pigments are used, as compared to when other colouring matter are used. Park and Shore (2004) stated that the exhaust dyeing of woven garments is a much more difficult task than that of exhaust dyeing of knitgoods, due to woven garments generally containing ancillary components, such as buttons, zips, linings and trims of different fibres.

Garments to be exhaust dyed are supplied either in greige, or prepared for dyeing (PFD) forms. Garments in greige form require a full scour/bleach procedure, while prepared for dyeing garments require a short scour to remove any auxiliaries, such as softeners, anticurls and lubricants, used to enhance the garment manufacturing processes (Chakraborty *et al*: 2005).

Cotton goods, destined for garment dyeing, are normally made up using unmercerised cotton threads to give inconspicuous solid-dyed seams. Conversely, subtly contrasting effects can be deliberately achieved using either mercerised cotton thread, to show up darker against the unmercerised garment panels, or polyester thread to remain undyed when the cotton panels are garment-dyed (Park and Shore: 2004).

Over the years, research was focused on improving the exhaust pigment dyeing process, with the aim of obtaining level dyeings with good fastness. The introduction of cationising agents brought about a revolutionary change in the field of exhaust pigment dyeing, as the presence of cationic charges on the cotton fibre enabled the pigment to be strongly attracted to the cotton fibre. Nevertheless, the overall success of exhaust pigment dyeing of cotton, in terms of obtaining level dyeings with good fastness properties has, however, not yet been reported.

1.5. SCOPE AND OBJECTIVE OF STUDY

The unpopularity of pigment dyeing of cotton garments, via the exhaust technique, is mainly due to the problems with unevenness and poor wet fastness to rubbing. The paybacks, however, far outweigh the drawbacks. A local garment dyeing company in the Durban Metropolitan area, Spectrum Textiles (Pty) Ltd, specialises in the exhaust dyeing of woven and knitted garments of all qualities. Since garments can only be dyed via the exhaust system, the company has investigated the exhaust dyeing of cotton garments using pigments, with the aim of achieving level dyeings instead of the “worn look”, in an attempt to reduce processing costs and environmental related problems, and improve lead times. They have, however, been experiencing fastness and levelness problems when exhaust pigment dyeing their cotton garments. In view of the fact that no ‘ready-made’ solution to these problems appeared to be available, it was decided to undertake a systematic study aimed at investigating the effects of various dyeing parameters on colour strength, levelness and fastness, with the intention of improving these.

The objective of the study was to optimise the exhaust pigment dyeing of cotton garments, in terms of obtaining level dyeings with good fastness and colour strength by varying the process routes and dyeing parameter concentrations/levels of cationisation, pH, Pigment, Binder/Fixer, Temperature and Material-to-Liquor Ratio.

The choice of equipment, for this research, was confined to a rotary drum machine used by Spectrum Textiles (Pty) Ltd. The effects of the dyeing parameters on the colour strength, wash fastness and colour fastness to rubbing of woven and knitted cotton pigment dyed garments were systematically investigated, with details on the choice of the concentrations/levels for each being given in Chapter 3.

The findings of this research would not only increase scientific and technical knowledge and understanding in this particular field but would also benefit Spectrum Textiles and other textile companies wanting to reduce processing costs and aiming towards a greener textile industry.

Chapter 2: Literature Review

2.1. INTRODUCTION

This literature covers the pigment dyeing of garments, in terms of fibre and fabric types, auxiliaries and pigments, machinery, and process routes. Literature, specifically covering the pigment dyeing of garments, was very scarce, with more information being available on the pigment dyeing of fabrics. The information contained in this chapter deals with cotton, colouration of textiles, pigment dyeing and the testing of pigment dyeings and focuses more on fabric than garments, the aim being to relate the information on fabrics to garments in the experimental design (Chapter 3).

2.2. COTTON

2.2.1. Introduction

Cotton is the purest form of cellulose (Gordon and Hsieh: 2007), and is the most important cellulosic and natural textile fibre in the world; being used to produce apparel, home furnishings, and industrial products. Cotton fibres are seed hairs from plants of the order Malvales, family Malvaceae, tribe Gossypieae, and genus Gossypium (Lewin: 2006). Many species are grown commercially, but they may be conveniently divided into the following three main types (Shore: 1995):

- *Gossypium hirsutum* (*G. hirsutum*), was developed in the United States from cotton native to Mexico and Central America, and includes all of the many commercial varieties of American Upland cotton. The staple lengths of the Upland cotton fibre vary from about 22 to 36 mm, and the micronaire value (an indicator of fibre fineness and maturity) ranges from about 3.8 to 5.0. Fibre from *G. hirsutum* is widely used in apparel, home furnishings, and industrial products (Lewin: 2006).

- *Gossypium barbadense*, which is of early South American origin, provides a fine fibre with the longest staple lengths. These fibres have a micronaire value of below 4.0 and a staple length usually greater than 35 mm. It is commonly known as Extra-Long-Staple (ELS) cotton, and includes the commercial varieties of Egyptian, American–Egyptian, and Sea Island cottons. The fibre from *G. barbadense* is used for the production of high quality apparel, luxury fabrics, specialty yarns for lace and knitted goods, and sewing thread (Lewin: 2006).

- Gossypium aboreum and Gossypium herbaceum, both of which are known collectively as ‘‘Desi’’ cottons, are the Asiatic or Old World short staple cottons. These are relatively coarse cottons and are the shortest staple cottons cultivated, ranging from about 9.5 to 19 mm in staple length, with a micronaire value greater than 6.0. Both are of minor commercial importance worldwide, but are still grown commercially in Pakistan and India. *G. aboreum* is also grown commercially in Burma, Bangladesh, Thailand, and Vietnam (Lewin: 2006).

Gossypium herbaceum and *Gossypium arboretum*, account for about 5% of global cotton production, with *Gossypium barbadense* also accounting for about 5%, and *Gossypium hirsutum* accounting for about 90% (Astruc: 2011).

The following section provides a breakdown of global fibre consumption, and illustrates the relative importance of cotton in this respect.

2.2.2. Cotton Market

According to the International Cotton Advisory Committee, cotton’s share of global fibre consumption decreased from 49.1% in 1990 to 27.6% in 2015 (Ethridge: 2016). There was a further decline of 3.3% from 2015 to 2016 (Lenzing Group: 2016), with the global cotton consumption being 24.3% in 2016, while that of synthetic fibres was 62.7% (Figure 2.1), of which polyester, the main competitor of cotton, accounted for about 55%.

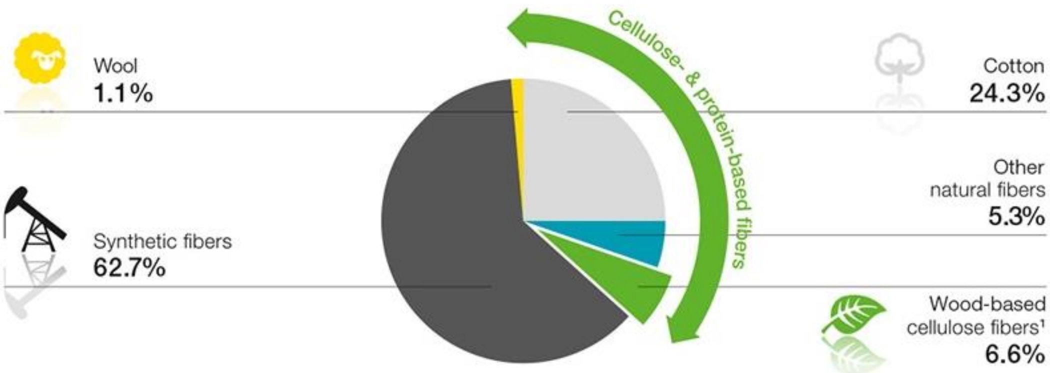


Figure 2.1 World Fibre Market Consumption. (Lenzing Group: 2016).

Although there has been a decrease in the demand for cotton, it still holds the largest share of the natural fibre market, and will continue to do so for many years to come, due to its wide variety of applications and demand.

It is important to understand the structure of the cotton fibre, particularly with its dyeing behaviour in mind. With this in mind, the next section discusses both the morphological and chemical structure of cotton.

2.2.3. Morphological Structure of Cotton

The morphological and chemical structure of cotton is closely related to its behaviour towards dyestuffs and chemicals during the dyeing process, and will therefore be the focus of the following sections.

A mature cotton fibre, being a flat ribbon, varies in width between about 12 and 20 µm. It is highly convoluted, with the number of convolutions varying between four and six per millimetre, reversing in direction every millimetre or so along the fibre. These characteristics make cotton easy to recognise under both electron and optical microscopes, Figures 2.2 (a) and (b) (Shore: 1995).

(a)

(b)

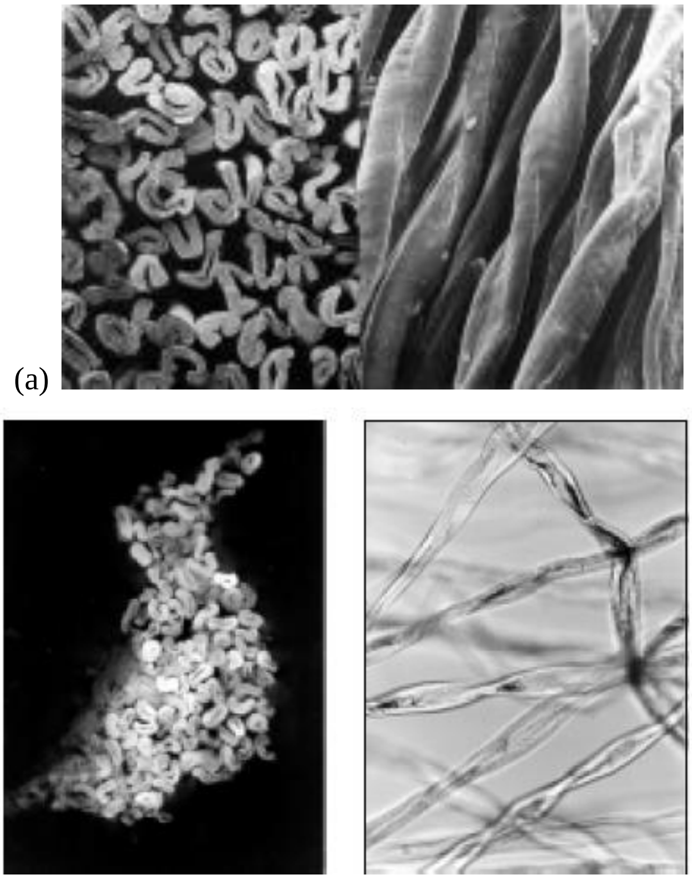


Figure 2.2 Micrographs of Raw Cotton (a) Scanning Electron and (b) Optical (Shore: 1995).

The dried cotton fibres have a bean-shaped cross-section. The bilateral structure is thought to originate from the asymmetry of mechanical forces in the fibres during drying after boll opening. The two highly curved ends of the bean-shaped cross section have the highest molecular packing density and are least accessible to reagents. The structure of the convex part is less dense and therefore more accessible to reagents. The concave section of the cross-section is the most accessible and most reactive portion of the fibres (Gordon and Hsieh: 2007).

The morphological structure of the cotton fibre encompasses various characteristics, such as the length of the fibre, the perimeter and diameter, the shape of the cross-section, and the thickness and fibrillar pattern in the walls. The wall of the cotton fibre is not homogeneous, but exhibits three main features: the cuticle, primary wall, secondary wall and lumen (Lord: 1961), as illustrated schematically in Figure 2.3.

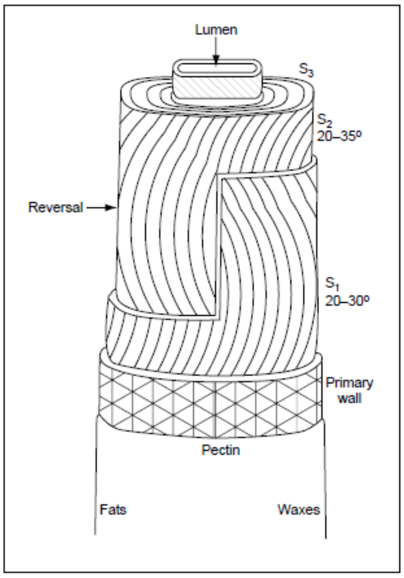


Figure 2.3 Idealised Diagram of Cotton Fibre Morphology (Shore: 1995).

The cuticle and primary wall are of paramount importance when using pigments, especially during the pre-treatment and dyeing stages. The cuticle consists essentially of surface deposition of cotton wax and a complex mixture of fats, waxes and resins (Lord: 1961), which render the fibre impermeable to water and aqueous solutions (Shore: 1995), and which therefore have to be removed to impart the necessary hydrophilic properties to the fibre.

2.2.4. Chemical Structure of Cotton

The primary wall, which encloses the nucleus and protoplasm, is built up from cellulose (Lord: 1961), and accounts for only 5% by weight of the fibre. A comparison of the composition of the primary wall with that of the cotton fibre as a whole, is essential, since the primary wall becomes disintegrated when preparing cotton for dyeing. The primary wall contains most of the non-cellulosic constituents (Shore: 1995), as well as a high proportion of other substances, some of which are similar to pectin (Lord: 1961), but are mostly water-soluble organic acids and sugars, as indicated in Table 2.1 (Shore: 1995).

Table 2.1 Comparative Data for a Typical Cotton (Shore: 1995).

Composition of a typical cotton

	Proportion of dry weight/%	
Constituent	Whole fibre	Primary wall
Cellulose	94.0	54.0
Protein (%N × 6.25)	1.3	14.0
Pectin	1.2	9.0
Wax	0.6	8.0
Ash	1.2	3.0
Other substances	1.7	12.0

Cellulose is a linear syndiotactic homopolymer, composed of D-anhydroglucopyranose units (AGU), which are linked together by β-(l,4)-glycosidic bonds. Each glucose unit contains three free hydroxyl groups (-OH) (Marsh: 1948), as illustrated in Figure 2.4.

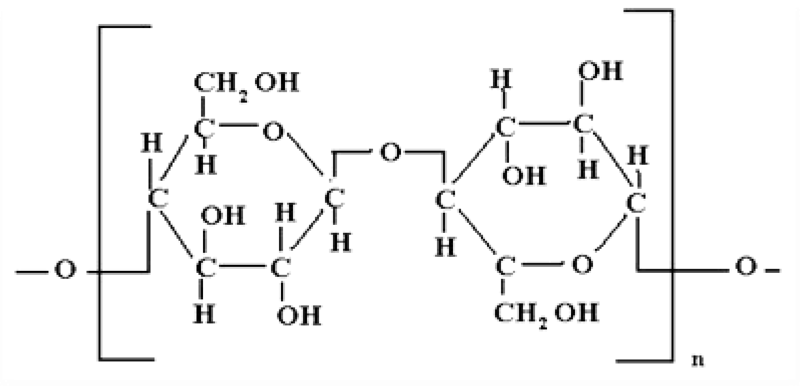


Figure 2.4 Chemical Structure of Cellulose (Shore: 1995).

The hydroxyl groups are important when the cotton fabric is treated with a cationising agent, for example during pigment dyeing (Ristić and Ristić: 2012), which modifies the cotton by producing cationic dye sites in place of the existing hydroxyl (-OH) sites (Choudhury: 2014), resulting in the higher adsorption of pigments.

The morphological and chemical structure of cotton also influences its properties in terms of chemical stability, which is important when dyeing, and is described in the next section.

2.2.5. Cotton Properties

Cotton is a relatively hydrophilic, water-absorbent fibre, with a standard regain of about 8% (at 65% RH), which rises to around 25 to 30% at 100% RH, at room temperature (Broadbent: 2001).

Cellulose shows remarkable stability towards strongly alkaline solutions in the absence of oxygen, even at high temperatures. It is, however, very sensitive to mineral acids, as these catalyse hydrolysis of the bonds between the glucose units and cause depolymerisation, eventually leading to the production of the monomer, glucose. Alkali boiling and bleaching always involve some degree of cellulose hydrolysis and oxidation, decreasing the average molecular weight of the polymer (Broadbent: 2001). Cotton's stability towards strongly alkaline solutions is advantageous when dilute and concentrated solutions of NaOH, are used in the pre-treatment and mercerisation of cotton, respectively. The pre-treatment, ensures the adequate removal of impurities, such as waxes, that make the fibres difficult to dye. The removal of these impurities, and the colouration process of cotton fabrics are detailed in Section 2.3.

2.3. COLOURATION OF TEXTILES

The goal of every dyeing is a coloured textile in the desired shade, homogeneous in hue and depth of shade, produced by an economic process and which exhibits satisfactory fastness properties in the finished state (Hunger: 2003).

Textile colouration mainly involves textile printing, dyeing and mass pigmentation of synthetic filaments during melt spinning (Johnson: 1989). Dyeing may occur at any stage during textile manufacture, for example on the fibre (i.e. stock dyeing), or on the intermediate forms, such as sliver or yarn, or on fabric, towards the end of the manufacturing cycle. Even garments and finished articles can be dyed (Broadbent: 2001). It is desirable, however, for it to occur as late as possible in the processing pipeline, preferably at the garment stage, so that the decision of colouration can be delayed as long as possible in order to cater for the dictates of fashion and quick response (Madaras *et al*: 1993).

Before delivery to garment manufacturing, the cotton fabrics are usually prepared continuously by using a sequence that normally will include singeing, desizing, scouring and/or bleaching and often mercerising. This is an added benefit in terms of quick response, since it shortens the processing time for the garment dyer, once a decision has been made about the colours that the market demands. If, greige (unprepared) fabric is delivered to the garment manufacturer, the garments have to be desized, scoured and/or bleached, depending on the brightness of shade required (Park and Shore: 2004), which in turn results in longer lead times.

2.3.1. Preparation for Dyeing

An essential stage, that precedes the actual process of dyeing, is that of pre-treatment. Natural or synthetic impurities in fabrics can interfere with wetting and dyeing. The objective of preparation is to remove as much of the unwanted impurities as possible so as to produce a fabric that will uniformly absorb dyes and chemicals (Broadbent: 2001). This could be in the form of scouring to remove waxes, and bleaching to obtain a white fabric when light colours need to be dyed. Fabric preparation is crucially important, because the successful outcome of all subsequent operations, such as dyeing, printing and chemical finishing, are critically dependent on it (Madaras *et al*: 1993).

2.3.2. Dyeing

The stage after pre-treatment is that of the colouration of the fabric. As stated previously, this can be achieved by either printing or dyeing, with the dyeing process being more widespread than printing.

Dyeing usually involves contact between an aqueous solution, or dispersion, of the dyes and the textile material, under conditions that promote substantivity and produce uniform colouration throughout (Broadbent: 2001). In contrast to this, pigments can be bound to the fabric structure by a polymeric binder, in pigment print or dyeing, or incorporated inside the filament during mass pigmentation (Cao: 2013) e.g. during, or prior to, extrusion in the case of filaments.

2.3.3. Post-dyeing Treatment

After dyeing, the material is rinsed to remove any adhering solution, but it may need additional treatment, while still in the dyeing machine. Broadbent (2001) suggested the following after-treatments:

- Washing in detergent, at, or near the boil, to remove any unfixed dye or loosely adhering dyes, auxiliaries and pigment from the fibre surfaces – this process is called soaping.
- Treatment with chemicals to improve the fastness properties of the dyeing – this often causes a change in shade and complicates colour matching.
- Application of simple finishing chemicals, such as softeners.

2.3.4. Classification of Dyes

In order to achieve good adsorption and uniform dyeings, the selection of dye is of the utmost importance and the differences between the major classes will now be discussed.

Dyes and pigments may be classified by their chromogenic systems, and this has been achieved in the Color Index (C.I.), published jointly by the Society of Dyers and Colourists and the American Association of Textile Chemists and Colourists (Color Index: 1971). The Color Index is the most comprehensive and authoritative reference work in the field, which provides technical information relating to fastness properties and methods of synthesis (Carr: 1995).

A simple classification into 2 groups was identified by the Color Index. Group 1 consists of Acid, Direct, Basic and Disperse dyes. These dyes are water soluble, although disperse dyes are only very sparingly soluble. Group 2 consists of Sulphur, Vat, Azoic, Phthalocyanines, Oxidation, Reactive, Chrome and Pigments (mass pigmentation and surface bonding) dyes, with the final state of the colourant being insoluble in the fibre in the form of large particles; thus giving rise to dyeings of high wet fastness (Color Index: 1971).

Due to different functional groups on the natural and synthetic fibres, various dyes form different bonds with the fibres, such as Van der Waals forces, hydrogen bonds and covalent bonds.

2.3.5. Dyeing Methods

2.3.5.1. EXHAUST DYEING

Exhaust dyeing is another term used for batch dyeing, and involves machines that are limited to the amount of goods that they can accommodate at any one time, with repeat loading necessary if the quantity to be dyed exceeds the capacity of the machine. Exhaust dyeing machines are constructed to ensure that the goods are in constant contact with the dye liquor. The liquor to goods ratio of the various batchwise dyeing machines ranges from about 5:1 to 30:1, or even higher (Ingamells: 1993). In the exhaust technique, all the material is in repeated contact with all the dye liquor during dyeing, and the fibres gradually absorb the dyes. The dye concentration in the bath therefore gradually decreases. Careful control of the dyeing temperature, pH and auxiliary chemical concentrations is often necessary to obtain level, well-penetrated dyeings (Broadbent: 2001).

Factors to be considered when dyeing via exhaust method (Broadbent: 2001):

- Amount of dye and colour yield

The amount of dyes used to produce the desired colour is usually expressed as a percentage of the weight of the dry material, and abbreviated as % owf, or % dye on the weight of fibre. With increasing amounts of absorbed dyes, the colour of the goods obviously becomes deeper, but also usually duller, and often with a slight change in hue. Deep shades frequently have lower fastness to wet treatments and rubbing than pale shades produced with the same dyes. On the other hand, deeper dyeings have higher light fastness. The colour yield is the depth of colour of a dyeing per unit amount of dye in the material.

- Liquor-to-goods ratio

The liquor-to-goods ratio (liquor ratio) gives the weight of the bath solution relative to the weight of the dry material being dyed. Many newer dyeing machines operate with lower liquor ratios in order to minimise the consumption of energy for heating the water. An increase in the liquor ratio generally causes a decrease in the level of exhaustion, under any given conditions, and therefore leads to a decrease in the depth of colour of the dyeing.

- Rate of dyeing

Dyeing should be neither too slow nor too fast. Slow dyeing involves long dyeing times, with increased risk of fibre damage and dye decomposition, particularly at higher dyeing temperatures. It is also very costly. On the other hand, very rapid dyeing will usually result in the colour being unlevel. The dyeing rate is influenced by the temperature and by the chemicals, such as salts and acids, all of which also influence the final exhaustion.

2.3.5.2. CONTINUOUS DYEING

Continuous dyeing is required when there are large volumes of goods, with the processing sequence being uninterrupted, from start to finish, and the goods moving at a constant rate throughout (Ingamells: 1993). In the continuous methods, the fabric passes through a small bath containing the dye solution and then two rubber-covered rollers squeeze out the excess solution. This process is called padding. Each small segment of fabric encounters the dye liquor only once, hence padding must be uniform across the fabric width and along its entire length. After padding, the dye must diffuse into the fibres. This step is called absorption. It may be as simple as rolling up the fabric and batching it for several hours, or as complex as a rapid thermal treatment in a steamer or hot air oven (Broadbent: 2001).

From the above literature, it can be concluded that the exhaust dyeing method for garments is preferable, since garments are dyed in small lots and can rapidly accommodate changes in fashion trends.

2.4. PIGMENT DYEING

2.4.1. Definition

Pigment dyeing is a process whereby pigment is bound to the surface of the fibre through the use of an appropriate binder, as in the case of cotton, or by mass pigmentation as in the case of synthetic fibres (Broadbent: 2001, Cotton Incorporated: 2000), whereby the pigment is mixed with the polymer chips, and then extruded.

2.4.2. Advantages and Disadvantages of Pigment Dyeing

Early attempts at pigment dyeing proved to be unsuccessful because of low exhaustion and poor uniformity, but later, more effective auxiliaries were introduced to improve dyeing quality (Kass: 1958).

Table 2.2. lists the advantages and disadvantages of pigment dyeing, and illustrates that the advantages outweigh the disadvantages, making the choice of this dye class favourable for certain applications, for example, where good wet rub fastness is not required.

Table 2.2 Advantages and Disadvantages of Pigment Dyeing (Miles: 2003, Aspland: 1997).

Advantages	Disadvantages
1. It is the simplest colouring process that consists of only dyeing, drying and fixation.	1. The wet rub fastness is generally poor.
2. It is a very economical process due to elimination of all wet after-treatments, lower labour and equipment demands.	2. The application of chemicals, such as binders can cause increased stiffness, presenting handling issues.
3. Pigments can be applied to most substrates, reducing problems in fibre blends.	

2.4.3. History and Overview

About 30 000 years ago, Palaeolithic man discovered the use of pigments for decoration purposes and as an application method for colouring fabrics. Some of the pigments used were earth pigments, such as natural iron oxides and carbon black from soot. Early prints on fabric tended, however, to be stiff and to fade easily (Aspland: 1997). The period following the Second World War was characterized by an intensive and focused development of pigment colourants, as aqueous dispersions of film-forming binders, which were composed of self-crosslinking copolymers, became available (Cao: 2013). These binders rendered the fabric less stiff and also improved fastness properties to some degree.

Colouration of textiles, using pigments, is becoming increasingly popular, due to the associated shorter processing sequences, lead times and lower environmental impact, as compared to other dyestuffs. Pigments, due to their insolubility and lack of affinity for the fibre, are usually in the form of dispersions and mixed into the dyeing solution containing binder and other auxiliaries (Cao: 2013) to enable the pigment to be securely attached to the fibre surface.

2.4.4. Pigments

Early pigments, known as earth pigments, were sourced from natural colouring matter, in the form of rocks, plants, animals, as well as natural iron oxides and soot; and were the earliest colourants used to decorate both people and their possessions.

Pigments, originating from rocks, were first recognized because their colours stood out when hard lumps of rock were examined, broken and then ground into a fine powder and blown onto the painting surface by a hollow tube, or mixed with fatty materials to form a natural paint, which was applied with the fingers or a reed. Plant extracts, such as Madder and Indigo, provided red and blue pigments respectively, while cochineal and lac lake were derived from insects, with the much-prized Tyrian purple obtained from certain shellfish, and finally sepia, from cuttlefish (Shore: 2002).

The era following the Second World War was the golden age for the development of pigments, in that the manufacture of inorganic pigments began in the 20th century, while the production of organic pigments has always been a part of the dyestuff industry since pigments became a secondary product of dyestuff manufacturing (Cao: 2013).

Pigments are molecular aggregates, insoluble in all media with which they come into contact during wet processing (Shenai: 1993), and can be mechanically dispersed in a specific medium to improve its colour or light-scattering properties (Denton and Daniels: 2002).

Pigments for textiles have no intrinsic substantivity for fibres and are not generally found in monomolecular (solution) form but rather in the form of very finely divided water dispersible particles which have a surface negative charge. The charge is due to the attraction of the hydrophobic tails of anionic dispersant molecules for the surface of the particles, while their hydrophilic anionic (negatively charged) heads project into any water surrounding the particles. This negative surface charge has been put to good use in textile colouration, for attracting the pigment particles to fibre surfaces on which cationic groups have been attached (Aspland: 1993).

Pigments are used as colourants in the physical form in which they are manufactured or obtained. The physical form means both the crystal structure and particle size distribution of the pigment. The physical form of dyes is becoming of increasing importance, as methods of handling them become more automated. Colouration with pigments is essentially a process of dispersion of solid particles of the pigment in a semi-solid medium (Shore: 2002), the pigment could be practically insoluble in one particular medium, yet dissolve to some extent in another. The partial solubility of the pigment is a function of the application medium and processing conditions, especially of the processing temperature (Herbst and Hunger: 2004).

Pigment molecules are required to be attracted strongly to one another in their solid crystal lattice structure in order to resist dissolution in solvents (Christie *et al*: 2000). Important application properties of pigments and/or pigmented systems, such as tinctorial strength, migration, recrystallization, heat stability, lightfastness and weatherability, are often determined by the portion of pigment that dissolves to a minor degree in the medium in which it is applied (Herbst and Hunger: 2004).

Pigments used in textile applications need to withstand hot alkaline washing, bleaching, and subsequent processes. Apart from the black (carbon black) and white (titanium dioxide) pigments extensively used in textile printing, the pigments employed in textile colouration are synthetic organic materials. The majority of textile pigments are based on the azo chromogen which provides yellow, orange, red and brown materials (Carr: 1995).

The colour of a pigment depends on the wavelengths of light not absorbed by the pigment, but rather the light reflected (Christie: 2000) at the pigment particle surface as well as the light penetrating the particle, which is then subject to multiple internal refraction before emerging. The refractive index of the pigment particle, relative to that of the medium in which it is embedded, is of great importance, because this affects the degree of light-scattering and transparency of the colouration. The relative contributions of these factors, to the final colour, depends on the particle size, and the production of a useful pigment involves finishing the raw pigment to optimise colour strength and covering power (Carr: 1995). Pigment particle sizes range from very fine colloidal particles (~0.01µm) to relatively coarse particles (~100.0µm) (Patton: 1973).

The manufacturing process of a pigment involves a number of stages; the first being synthesis, in which the sequence of chemical reactions is carried out. However, this synthesis does not necessarily give the optimised product for a particular application. In the second phase of the process, commonly referred to as conditioning, the product is developed into an appropriate crystalline form, with a controlled particle size and shape distribution, and the surfaces of the particles may be altered by suitable treatments (Christie *et al*: 2000). Furthermore, depending on the particular pigment, these two phases may be either distinctly separate or combined into a single process. Finally, the pigment is subjected to finishing, in which it is converted into a form which is acceptable to the user (Christie *et al*: 2000).

2.4.5. Classification of Pigments

Pigments are generally classified as either organic or inorganic (Christie *et al*: 2000, Herbst and Hunger: 2004), although Shore (2002) maintained that pigments can be divided into three main series, according to their chemical constitution, namely organic pigments, inorganic pigments and water insoluble dyes.

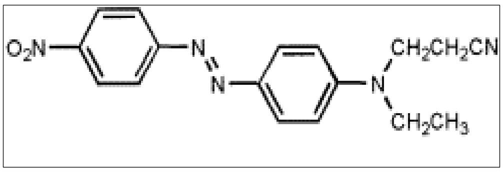
Buxbaum (1993) stated that inorganic pigments account for approximately 96% of the 5 million tonnes of pigments produced worldwide. Shore (2002), on the other hand, stated that inorganic pigments and water insoluble dyes each accounted for approximately 20% of the total number of pigment products, with organic pigments accounting for the balance of 60%. Since water insoluble dyes are decreasing in importance, the focus here will be on organic and inorganic pigments.

Generally, organic pigments are characterised by high colour strength and brightness and variability in the range of fastness properties which they offer. Inorganic pigments generally provide excellent resistance to heat, light, weathering, solvents and certain chemical attacks. In this respect, they have technical advantages over most organic pigments, although they suffer from the disadvantage of considerably lower intensity and brightness of colour compared to organic pigments. Additionally, inorganic pigments are usually significantly cheaper than organic-based materials (Christie *et al*: 2000).

2.4.5.1. ORGANIC PIGMENTS

Organic pigments can be classified as either classical or high performance pigments. Classical organic pigments mainly consist of azo pigments and phthalocyanines, as indicated in Figures 2.5 (a) and (b), respectively in terms of their Color Index (C.I.) numbers. These organic pigments are relatively inexpensive products and used extensively in a large range of printing ink, plastics and paint applications. High performance pigments are more sophisticated in nature and are able to provide greater technical performance, usually at higher cost (Christie *et al*: 2000).

(a)



(b)

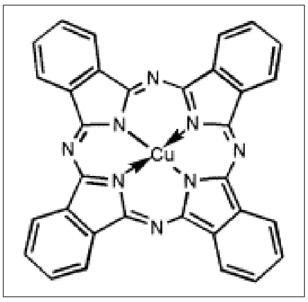


Figure 2.5 Chemical Structure of (a) Monoazo pigment, C.I. Disperse Orange 25 and (b) Copper Phthalocyanine, C.I. Pigment Blue 15 (Christie *et al*: 2000).

Organic pigments, used in textile colouration, are sourced from chemically refined oil, and are entirely aromatic-organic or organo-metallic co-ordination compounds (Aspland: 1993).

Organic pigments are typically non-ionic colourants and based on various chemical chromophoric classes (Shore: 2002, Zollinger: 1991), usually being brighter, purer, and richer in colour than comparable inorganic pigments (Patton: 1973). They can be treated with a suitable surfactant and milled in order to reduce and optimise the particle size (typically 0.03-0.5µm) and improve colour strength (Shore: 2002). The coloured organic pigments are mostly used in the form of printing inks, followed by paints and plastics. They are commonly used to print postage stamps and currency notes, and for safety reasons, different coloured organic pigments can be used to identify and differentiate cable coatings, gas conduits, electrical switches, yellow school buses etc. (Hao and Iqbal: 1997).

2.4.5.2. INORGANIC PIGMENTS

Inorganic pigments play a special role in pigment chemistry for several reasons. Some of them are relevant to culture heritage and history, such as the earth pigment colours of oil paintings in the art galleries around the world. Another reason behind the importance of inorganic pigments lie in the availability of white, which is not so for organic pigments (Shore: 2002).

Inorganic pigments may be obtained from naturally occurring mineral sources, or which have been obtained synthetically. Inorganic pigments exist as the coloured natural minerals commonly used to embellish ceramics, glass and many other artefacts (Shore: 2002). Some of them are single-component particles, such as oxides, hydroxides or sulphides, while others are mixed-phase pigments, which contain mixed crystals of oxides or sulphides, which are distinct from pigments that are pure physical mixtures (Cao: 2013).

Inorganic pigment, in nature, crystallises as a stable oxide lattice and the colour occurs by reason of the incorporation of coloured metal cations in a variety of valency states (Schwarz and Endriss: 1995). Some inorganic pigments are still in use commercially, and they can be classified further as non-coloured pigments (hiding white pigments, non-hiding white pigments, black pigments and metallic pigments) and coloured pigments (Christie *et al*: 2000). White pigments are fundamental to provide opacity to the paints and printing inks, which are used on metal, wood, paper, textile fabrics and plastic films, and are also applied to provide opacity to synthetic fibres and plastics produced by moulding and extrusion processes (Shore: 2002).

2.4.6. Pigment Dyeing Systems

Pigment dyeing, or colouration, processes or systems, can be subdivided into pigment exhaust dyeing and pigment pad dyeing. Although both exhaust and pad dyeing with pigments is possible for cotton fabrics, only exhaust dyeing is suitable for garments.

2.4.6.1. PAD DYEING OF PIGMENTS

The padding system of pigment dyeing uses machines similar to those used in continuous dyeing, essentially consisting of a padding process followed by a fixing process. The ingredients needed in a conventional pigment pad bath are the pigment dispersion, binder dispersion, anti-migration agent, wetting agent and, for some acrylic binders, ammonia; occasionally some defoamer may also be used (Aspland: 1997).

Problems occurring in pigment padding can be attributed to the following reasons (Aspland: 1997):

- The fabric preparation.
- The mix (mixing procedure, agitation/stirring, straining, incompatibility).
- The binder (amount, type, build-up).
- The pigment (amount, type, build-up).
- Migration on drying (anti-migrant and equipment).
- The auxiliary chemicals and the curing conditions.

2.4.6.2. EXHAUST PIGMENT DYEING

The word exhaust implies a batch process and although the pigment cannot diffuse into the fibre, it does migrate from the dyebath to the fibre surface (Aspland: 1993). Exhaust pigment dyeing is commonly used for cotton garments. In addition to the pigment, exhaust pigment dyeing of cotton generally also requires a cationising agent, binder, softener, cross-linking agent, wetting agent and an agent for cleaning the equipment. For cotton, the application system consists of four stages; cationisation, pigment exhaustion, binder exhaustion and drying (Cotton Incorporated: 2004, Cao: 2013).

(a) Cationization

Cellulose fibres carry a small negative change ($\zeta_{plateau}$ = -11mv), due to the presence of some carboxylic acid groups from oxidation at the primary hydroxylic sites (Kumar *et al*: 2013, Stan-Kleinschek and Ribitsch: 1998), and exhibit a negative zeta potential when immersed in water (Fang: 2010). Since pigments have a surface negative charge (Aspland: 1993), an electrostatic repulsion, between the cellulose fibres and pigments, results in low colour yield (Fang: 2010). As a result of this, a number of studies have been carried out on introducing cationic sites into the cotton fabric to improve the pigment uptake and colour fastness properties (Burkinshaw *et al*: 2000, Kin *et al*: 2004, Kumar *et al*: 2013). To this end, the cotton fabric is treated with a cationising agent (Ristić and Ristić: 2012), which modifies the cotton by producing cationic dye sites in place of the existing hydroxyl (-OH) sites (Choudhury: 2014), thereby reducing the electrostatic repulsion, resulting in a positive effect on adsorption of pigments onto the cotton (Ristić and Ristić: 2012). The excess cationising agent is rinsed off the cotton fabric (Aspland: 1993) which is then exhaust dyed with the pigment. Nevertheless, the problem of unevenness continues to be a matter of concern (Chottopadhyay: 2001, Lewis and Lei: 1991).

The commonly used cationic agents are either tertiary amines or quaternary ammonium compounds (Kumar *et al*: 2013, Wu and Chen: 1992/1993). They can be reacted with cellulose fibres under a variety of application conditions, such as exhaust, pad-batch, pad-bake, pad-steam, jig-exhaust and jet-exhaust (Wang: 2009). Other cationic agents, such as 3-chloro-2-hydroxypropyltrimethylammonium chloride (Hauser and Pslopek: 2005, Kumar *et al*: 2013), Trimethylol melamine (TMM), and Polyepichlorohydrin Dimethylamine N-metylolacrylamide (Kumar *et al*: 2013, Nakpathom and Phromphen: 2008), are commonly used in the modification of cotton fibres.

Kumar *et al* (2013) conducted a study to examine the influence of pH, temperature, contact time and concentration on the adsorption of pigment on cationised cotton. The study included 4 cationizing agents applied at acidic pH of 2, 4, 5 and 6, temperatures of 30ºC, 50ºC, 70ºC and 100ºC, pigment concentration of 4% owf and material-to-liquor ratio of 1:100. Their study showed that the amount of pigment adsorption on cationised cotton increased with pH, with the best uptake recorded at pH 5. At pH higher than 6, unfavourable dyeing conditions occurred. It was also concluded that an increase in temperature from 30ºC to the boil was accompanied by an increase in pigment adsorption, with the optimal adsorption being observed at 70ºC.

Wu and Zhang (2013) conducted cationisation trials on cotton/polyester fabric and concluded that when the cationising agent levels were less than 5g/l, the K/S values increased, whereas when the levels were greater than 5g/l, there was a decrease in K/S values. It was also concluded that, when the temperature increased from 50°C to 70°C, K/S increased, whereas a further increase in temperature from 70°C to 100°C, led to a decrease in K/S; the optimum temperature being considered to be between 60°C and 80°C.

(b) Binders

Any pigments applied to textile fibres from an external medium, such as a pad liquor, colour bath or print paste, will require the additional use of polymeric materials, known as binders, to encapsulate the particles deposited on the fibre surface and hold them on the surface by virtue of the adhesion between the fibre and the binder. This adhesion has nothing to do with the pigment, but depend solely on the characteristics of the binder (Aspland: 1993). The binder is vital in linking the pigment and fibre, and influences the colour durability (Whistenant: 1995), thus must be stable to outside forces that would tend to dislodge the pigment from the textile, such as washing or rubbing (Cotton Incorporated: 2004), thereby revealing the unpigmented base colour of the fibres beneath (Aspland: 1993).

Binders should possess the following traits (Cotton Incorporated: 2004):

- Inexpensive
- Provide good colour yield
- Non toxic
- Soft
- Wash fast
- Provide good crockfastness
- Easily polymerized
- No stain and build up on equipment
- Non-yellowing
- Not affect lightfastness
- Be stable in application

Most binders in use today are applied in aqueous systems (Aspland: 1993), with some 40-45% binder solids incorporated into the water (Schwindt and Faulhaber: 1984). The binders are in the form of dispersions of water insoluble droplets, composed of low molecular weight prepolymers (macromolecules), often based on acrylates, styrene acrylates, styrene butadienes or vinylacrylates. The droplets are comparable in size to the pigment particles, and are usually less than 0.5 microns in diameter (Aspland: 1993). On heating, evaporation of the solvent or other dispersion medium occurs; enabling the binder particles to coalesce to form a thin coherent coating, which is several microns thick, enclosing the pigment particles and adhering to the fibre (Schwindt and Faulhaber: 1984).

The resistance to removal of a particular binder film may be enhanced by including reactive groups in the macromolecules of the binder which, under curing conditions, cause the binder polymer molecules to crosslink with others to form a much more intractable polymer network. The crosslinked polymer will swell less readily, which will enhance the durability of the film to wet treatments. Nevertheless, excessive crosslinking can result in the film becoming too rigid and the desired hand can be lost (Aspland: 1993).

Binders are usually produced from synthetic polymers, although the potential of natural wood resin, wax, linseed or safflower oils and chitosan has also been investigated due to their biodegradability. After industrial trials, chitosan was identified as the best of these biodegradable binders, and such an ecologically friendly binder is already in production (Karypidis: 2000).

(c) Auxiliaries

- Softeners

Apart from appearance, the handle of the textile is also very important (Schindler and Hauser: 2004). The binder utilised in pigment dyeing usually produces a stiffening of the fabric and harsher handle (Karypidis: 2000), hence almost all pigment dyed apparel and home furnishing textiles are treated with softeners (Schindler and Hauser: 2004). Most softeners are composed of molecules having both a hydrophobic and hydrophilic constituent. According to their ionic nature and structure, softeners can be subdivided into cationic, anionic, non-ionic and silicone types (Lacasse and Baumann: 2004, Wei: 2009). These softeners can lower surface friction, decrease stiffness, enhance rub fastness (Miles: 2003) and impart a considerably softer hand (Lacasse and Baumann: 2004).

Since cotton possess a negative charge, when immersed in water, cationic softeners are electrostatically attracted to the fabric surface (Karypidis: 2000), and are therefore most widely used for the pigment dyeing of cotton, to achieve the best results. Their cationic character is typically based on a positively charged quaternary ammonium ion (Karypidis: 2000, Shore: 2002).

- Crosslinking Agents

A crosslinker may also be incorporated into the binder formulation to enhance the colour fastness of the pigment dyed fabric (Thompson: 1995). These chemical agents increase the fabric stiffness and also generally its mechanical performance (Miles: 2003). The crosslinking process is typically a condensation reaction, involving formaldehyde-based derivatives, which eliminate water, and are required when the binder has no self-crosslinking groups, just reactive groups for bonding to the substrate. When crosslinkers are applied to cellulosic fibres, chemical bonds will also be formed between the binder and the fabrics. A crosslinker should be selected on the basis of optimised temperature, pH and curing time. In addition, the reactivity of the crosslinker needs to be considered in order to ensure that premature reaction does not occur in the pigment dye bath, leading to damage of the subsequent film formed by the binder particles, or even cause the pigment solution to gel (Schwindt and Faulhaber: 1984).

- Wetting Agents

Wetting agents, also referred to as surfactants, are additives which expel air from the textile assembly contained in the aqueous processing bath and lower the fibre/fabric surface tension, thereby increasing spreading of the dyebath ingredients and improving uniformity of the binder (Lacasse and Baumann: 2004). Wetting agents, are typically non-ionic or anionic in nature, with non-ionic surfactants generally proving to be the best in practise (Nettles: 1983).

- Agents for Cleaning of Equipment

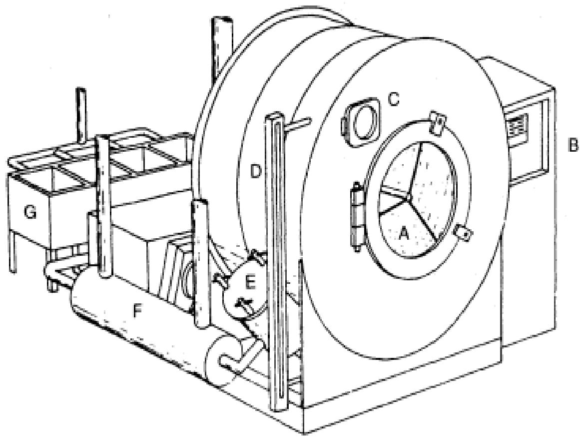
The gradual build-up of the somewhat intractable pigment particles on equipment generally requires the timely use of a reductive clearing treatment. Such a clearing treatment usually involves caustic soda and thiourea dioxide, or an oxidative treatment, with calcium hypochlorite, followed by a sodium bisulphite antichlor (Aspland: 1993).

2.4.7. Garment Dyeing Machines

Garment dyeing machines are generally rotating machines, similar to large-size industrial washing machines (Bellini *et al*: 2001). Different types of machines have been developed to handle the various shapes and sizes of garments, most designed to operate at atmospheric pressure, but high-temperature machines for dyeing garments containing textured polyester yarns, have also been developed. Care has to be taken to avoid damage to the garments by the machine components, and all surfaces which come into contact with the garments must be perfectly smooth. Also, the fluid flow must not be too vigorous to cause damage (Christie *et al*: 2000). Side paddle machines, of stainless steel construction, may be used for garment dyeing (Cawood and Scotney: 2000). Nevertheless, due to the awkward unloading of the machine, rotary drum machines have become more popular for garment dyeing.

2.4.7.1. ROTATING DRUM MACHINES

The development of garment dyeing machines, enabling markedly lower liquor ratios, has produced major savings in resources. Such machines resemble an industrial version of a front-loading domestic washing machine (Park and Shore: 2004), and consists of a perforated drum, which is mounted horizontally in the main vessel, which encloses it. The garments are loaded into the drum and the drum then rotated slowly in the dye liquor contained within the main vessel. As the drum rotates, the garments ride up its inner wall and then fall back to the bottom under gravity, so that the liquor agitation is very effective (Christie *et al*: 2000). Figure 2.6 illustrates a typical rotating drum machine used for garment dyeing with liquor ratios of 1:10, or even lower, being possible, and dyeing being carried out with the cage rotating at 3 to 35 rpm, with drum reversal every 20 to 30 seconds. Hydro-extraction is carried out at 500 rpm (Park and Shore: 2004).



A – Perforated Drum (with Y-pocket)
B – Control Panel
C – Sampling Port
D – Liquor Level Indicator
E – In-Line Lint Filter
F – Heat Exchanger
G – Addition Tanks

Figure 2.6 Diagram of a Typical Rotating Drum Garment Dyeing Machine (Christie *et al*: 2000).

Some rotating drum machines consist of two drums, rotating side-by-side within the main vessel (Christie *et al*: 2000), these being beneficial for larger garments lots. Further developments include three-pocket drums with centre-shaft injection of liquor; which give better liquor circulation, leading to lower drum speeds and better fabric appearance. These machines are particularly suited for processing woven garments, cotton knitwear and some hosiery, as well as short lengths of upholstery fabric (Cawood and Scotney: 2000).

The advantages of rotating drum machines include the following (Park and Shore: 2004, Broadbent: 2001):

1. Low liquor ratio with savings in resources.
2. Dry loading to hydro-extracted unloading
3. Optional basket geometry of open, D- or Y-pocket configurations, allowing one, two or three compartments.
4. External liquor circulation.
5. High-speed hydro-extraction.
6. High-temperature capability.
7. Control systems for time/temperature, rotation profile and dispensing dyes and chemicals.
8. Sophisticated design for heating and cooling, with heat exchanger and heat recovery.
9. Variable rotation speed for the dyeing operation, with drum reversal.
10. In-line lint filter.
11. Tilting mechanism for ease of unloading.
12. More efficient and cleaner to operate.

Despite the fact that garment dyeing accounts for only 6% of textile production, there has been intensive development, particularly in Italy, of rotating drum dyeing and hydro-extraction machines, such as the Flainox NRP. Such machines have control and dispensing systems, with a load capacity of 50 to 150 kg, operating at a liquor ratio of 1:8. In the Bellini Robotel machine, a liquor ratio of 1:3 is possible for the dyeing stage and 1:15 for washing-off (Park and Shore: 2004). The rotating drum dyeing machine used in this study is described under "Experimental".

2.4.7.2. FINISHING MACHINE

In most cases, the finishing process for garments, consists of a steaming treatment, to remove creases or to relax the garments. This is achieved by using driers, which are often constructed to incorporate tumblers, consisting of a perforated drum, equipped with a heating unit, air suction unit, circulation unit and a lint sieve device; with the steam blown outwards through the garment which is under a low tension (Saravanan and Ramachandran: 2008).

The finishing machine used in this study is described under "Experimental".

2.4.8. Exhaust Pigment Dyeing Systems

Two systems, as described by Cotton Incorporated (2004), may be employed for the exhaust pigment dyeing of cotton garments. The first system requires the fabric to be cationised, followed by pigment exhaustion, binder exhaustion and, finally, drying. The second system requires the binder to be exhausted immediately after the cationic agent is applied. The fabric is then rinsed, followed by the addition of the pigment. This method does tend to produce more uniform dyed appearance, but the dye fastness is decreased.

2.4.9. Rectifying Undesirable Outcomes of Pigment Dyeing

Table 2.3 lists suitable corrective measures that could be implemented when pigment dyed garments have undesirable properties such as poor rub fastness and wash fastness.

Table 2.3 Recommendations for Rectifying Undesirable Outcomes of Pigment Dyeing (Cotton Incorporated: 2004).

Undesirable Outcomes	Recommendation
Poor Dry Crock	Increase Binder
Poor Wet Crock	Re-wash
Poor Abrasion	Add Softener
Poor Wash Fastness	Increase Binder
Poor Colour Yield	Increase Pigment % on weight of fabric
Poor Appearance	Dyeing Procedure
Binder Kicking out of Bath	pH Compatibility

2.5. COLOUR MEASUREMENT

The following section provides the theoretical background to light and colour, and explains the principles of colour measurement.

The basis of all colour measurement work is the Commission Internationale de l'Eclairage (C.I.E.) system of colour specification, agreed upon in 1931. The C.I.E. is an organisation devoted to international cooperation and exchange of information among its member countries on all matters relating to the art and science of lighting (Christie *et al*: 2000).

Colourimetry is an objective method, and therefore more accurate and reproducible than subjective visual assessment, and is thus widely used today. Colour, a three-dimensional quantity, is expressed by a set of three numbers, referred to as colour coordinates, which are typically the values of colour strength, hue, and chroma (Hunger: 2003). This study focuses on colour strength only, which indicates how strongly coloured the specimen is.

Substances absorb light (or radiation) in specific regions of the visible spectrum, with the selective absorption of radiation giving rise to their individual colour. The colour seen, depends on the wavelengths of light reflected by the substance, in this case, the pigment (Christie: 2000). In colour measurement, the wavelength region of interest encompasses electromagnetic energy of wavelengths from approximately 400 nm (violet) to 700 nm (red) (Fairchild: 2005). Further to this, the colour observed, also depends on the sources of light under which coloured materials are viewed, such as daylight (D65), tungsten (A) and the various fluorescent types of light (Christie: 2000). With pigment dyed garments, this will entail using D65 illuminant, on the spectrophotometer and in the light box, for evaluating colour strength and wash and rub fastness.

All garments for this research were dyed using Blue pigments, therefore focus should be drawn to the wavelengths of 435 to 480 nm, as indicated in Table 2.4, which lists the colours associated with their respective wavelengths.

Table 2.4 Perceived Colours in Relation to Various Electromagnetic Wavelengths (Bamfield: 2001)

Wavelength (nm)	Perceived Colour
380 - 400	Violet
400 – 435	Indigo
435 – 480	Blue
480 - 490	Greenish Blue
490 – 500	Bluish Green
500 – 560	Green
560 – 580	Yellow Green
580 – 595	Yellow
595 – 605	Orange
605 - 740	Red

2.5.1. Colour-Measuring Instruments

There are two basic types of instrument for colour measurement, spectrophotometers and photoelectric tristimulus colourimeters. The spectrophotometer is the most fundamental instrument for colour measurement, and does not measure the colour of a material directly (Christie: 2000), but rather generates wavelength-by-wavelength analysis of the light reflected or transmitted by an object (Park: 1993), the values so derived being used to compute the tristimulus values (Christie: 2000). Tristimulus colourimeters, on the other hand, use filters and approximate to the spectral distribution of the CIE standard observer; they measure colour in terms of various parameters, such as x,y,z or L,a,b (Park: 1993). For this research, colour measurement was carried out using a spectrophotometer.

2.5.1.1. SPECTROPHOTOMETERS

Spectrophotometers are used to measure the reflectance values of coloured materials, and are interfaced with dedicated microcomputers (Christie: 2000) to enable them to transform the information by tristimulus integration into numerical values of colour at each wavelength (Ohta and Robertson: 2005). A spectrophotometer makes use of a light source to illuminate the sample, using a specific illumination and viewing geometry. Reflected or transmitted light is then passed on to the spectral analyser, where the light is split into its spectral components. This allows the light detector and control electronics to make measurements at many points across the visible spectrum (McDonald: 1997). Some spectrophotometers give reflectances at every 20 nm, between 400 and 700 nm while others give the values at every 10 nm, between 380 and 710 nm (Christie: 2000), as used for this research.

2.5.2. Colour Strength (K/S)

When increasing concentrations of pigments are applied to a textile, the reflectance at each wavelength decreases. Gradually a limit is reached, whereby increasing the concentration of pigment still further does not reduce the reflectance any further (Christie *et al*: 2000).

The colour strength of a sample, is a single numerical value related to the amount of colourant contained in the sample and is based on spectral data. The strength of the colourant can be measured in terms of the Kubelka-Munk (K/S) value, which has been derived from the Kubelka-Munk function (R) (Tayyebkhan: 1996).

$$K/S_{\lambda} = \frac{(1 - R_{\infty})^2}{2R_{\infty}}$$

Where, R_{∞} = reflectance of light of a particular wavelength from a sample of infinite thickness, K, the absorption coefficient and S, the scattering coefficient.

K/S value shows dyeing depth with the deeper the depth of dyeing, the greater the K/S value (Wu and Zhang: 2013). Colour strength, by a single wavelength method, can be measured at a specified wavelength (λ) of maximum absorption using the above equation (Tayyebkhan: 1996). By measuring reflectance (R) with a spectrophotometer, K/S can be determined. The samples, usually folded four times, are held on the spectrophotometer measuring port. The spectrophotometer is calibrated under white, black and green standards with the following settings: USVP, 10˚ Standard Observer, UV/Specular excluded (Hunger: 2003).

For this study, only the colour strength will be taken into account as it forms the basis of all statistical analyses and physical testing conclusions.

2.5.3. Colour Fastness

The definition of colour fastness, as proposed by the American Association of Textile Chemists and Colourists, is as follows: ‘The resistance of a material to change in any of its colour characteristics, to transfer its colourants to adjacent materials, or both, as a result of the exposure of the material to any environment that might be encountered during the processing, testing, storage, or use of the material’ (AATCC: 2005).

The transfer of colour from one dyed fabric to another white fabric, by rubbing, may be due to the presence of superficial dyes in dark shades, inadequate washing at the end of dyeing, formation of few coloured molecules at the textile-air interface, water solubility of dyes or weak dye-fibre attachment on the surface layer. Generally, the wet rub fastness test tends to produce a lower result than the dry rub fastness test; which may be due to solubilisation of a part of the dye and its migration to the surface of the dyed fabric (Clark: 2011). In terms of pigment dyeing, which is a surface colouration of the garment, the pigment is held in place by the use of a binder or fixer, which determines the fastness properties. Should the binder/fixer be applied in small quantities, there is a higher possibility that the pigment would not securely be bound to the surface of the garment, leading to poor fastness. On the other hand, a large quantity of binder/fixer would render the garment to be harsher in handle.

2.6. CONCLUSION

Garment dyeing, using various dyestuff, has been practiced since the 1900s, originally with the main objective of over-dyeing. The introduction of pigments in the exhaust dyeing of cotton garments, from the 1980s, brought about a weathered look in the garments; which lead to a new fashion trend. Nevertheless, the pigment dyed cotton garments exhibited poor wet fastness properties. Due to the simple process and limited after-treatments required in the pigment dyeing of cotton garments, intensive research aimed at obtaining level dyeings, was carried out from the year 2000, the focus being mainly on the cationisation process, which modifies the cotton by producing cationic dye sites, thus giving cotton and pigment substantivity for each other.

Previous studies as mentioned in the literature review on the cationisation of cotton fabrics, as well as garments, in relation to pigment dyeing used cationising concentrations from 2% to 12% (owf), with good results on colour strength being reported for cationising concentrations between about 6 and 8%. Studies using pigment concentrations from 1% to 5% (owf) resulted in unlevel dyeings and poor wet rub fastness rating of 3/4 and 3. Beaker dyeing investigations on the effect of pH on cationised cotton, using pH levels of 2, 4, 5 and 6, concluded that a better pigment uptake occurred at pH 5. Investigations on binder concentrations (owf) at 3, 5, 7 and 10% on cotton fabrics, showed that 5% binder provided the best results. Studies on the effects of temperature on cationisation from 50° - 100°C concluded that temperatures higher than 80°C yielded a lower pigment uptake, with that of 60°C being concluding as having the best dye uptake for the Blue pigment. Research only focused on material-to-liquor ratios of 1:20, however ratios ranging from 1:3 up to 1:30 or higher were suggested.

According to the literature review, no solution has yet been found for the poor wet fastness of exhaust pigment dyed cotton garments, with the factors appearing to play a role in this regard, being cationisation, pigment and binder concentrations, pH, temperature and material-to-liquor ratio; with all the aforementioned factors being either independently or partially investigated.

2.7. PRESENT STUDY

In the light of the above Section 2.6., the present study systematically investigated the effect on K/S, wash fastness, and wet and dry rub fastness by systematically varying these factors/parameters, as well as investigating that of the two different dyeing process routes, the first route includes pigmenting the garment followed by the application of a binder/fixer, and with the second route applying the binder/fixer followed by pigmenting of the garment. The choice of varying the parameters and process routes was aimed at gauging their effects on the colour strength, wash fastness and colour fastness to rubbing; on woven and knitted cotton pigment dyed garments.

Based on earlier studies, it was decided that the following concentrations/levels, namely; cationisation concentrations of 4, 6 and 8% (owf), pH levels of 3, 5 and 6, for both the pigment and binder, Blue pigment concentrations (owf) of 5, 7 and 9 %, binder/fixer concentrations of 3, 5 and 7 % (owf), temperatures of 60, 70 and 80°C and material-to-liquor ratios of 1:8, 1:15 and 1:20 will be used for the present study.

Chapter 3: Research Methodology and Experimental

3.1. INTRODUCTION

The research was focused on investigating the exhaust pigment dyeing of woven and weft knitted cotton garments and ultimately, practical ways of improving the levelness and wet fastness properties of the dyed garments. Samples were prepared from pre-treated cotton fabrics of both woven and weft knitted qualities and were made-up to mimic an actual garment, and will, hereafter, be referred to as “garments”, for the sake of simplicity. Trials were carried out using Blue pigments, obtained from two different dyestuff suppliers, and which were applied by varying 6 process parameters on 3 levels each (Table 3.1.), as well as by changing the pigment dyeing process route (Table 3.2).

Table 3.1 Levels at which the 6 Parameters were Varied.

Varied Parameters	Concentration % / Range
Cationization	4, 6 and 8 % owf
pH	3, 5 and 6
Pigment	5, 7 and 9 % owf
Binder / Fixer	3, 5 and 7 % owf
Temperature	60, 70 and 80°C
Material-to-Liquor Ratio	1:8, 1:15 and 1:20

Table 3.2 Two Process Sequences used for Pigment Dyeing.

Sequence 1	Sequence 2
Scour	Scour
Cationize	Cationize
Pigment Dye	Bind / Fix
Bind / Fix	Pigment Dye
Soften	Soften
Dry	Dry

The results obtained, after testing of the pigment dyed garments, were used to gauge the influence of changing these parameters on the levelness, colour strength (K/S) and wet fastness properties of the dyed garments.

3.2. MATERIALS AND EQUIPMENT

3.2.1. Fabrics

Cotton fabrics, both woven and weft knitted, were chosen for this research as they represent the main share of the relevant market. Further to this, cotton garments hold the major share of pigment dyeing at Spectrum Textiles, where the trials were undertaken.

The plain weave fabric used in this research comprised 100% open-end spun cotton yarns, while the weft knitted fabric comprised 100% ring-spun cotton yarns, Figures 3.1 (a) and (b), respectively.

(a) (b)

Figure 3.1 Microscopic View of (a) Open-End Cotton Yarn and (b) Ring-Spun Cotton Yarn (Durban University of Technology: 2017).

Generally, fabrics used to produce garments have been through various pre-treatment stages, such as singeing, desizing, scouring, bleaching and finishing. It was, therefore, decided that "prepared for dyeing" (PFD) cotton fabrics would be used for this research, as it would reduce the processing time and pre-treatment costs. For this research, the PFD fabric would need to be sewn on three sides to mimic a garment, which would then require a light scour to remove any impurities due to handling.

Prior to the PFD fabrics being made up into garments, fabric analysis on both the woven and weft knitted fabrics were conducted at the Textile Technology Laboratory at the Durban University of Technology, using a Zweigle fabric sample cutter, a Denver Instrument XL-410 scale, a Leitz Laborlux 11 microscope at 10 x magnification and a James H. Heal Twist tester, with the results being given in the next section.

3.2.1.1. WEFT KNITTED FABRIC

Ring-spun yarns were selected for the weft knitted fabric, since they are most popular and readily available in the market, and generally the choice of Spectrum Textiles. The fabric was a 160 g/m^2 single jersey structure, knitted from a 20 tex Z, 600 tpm, 100% unmercerised cotton yarn, with 15 wales and 20 courses per centimetre, respectively, with a microscopic view of the knitted fabric indicated in Figure 3.2.

Figure 3.2 Weft Knitted Fabric (Durban University of Technology: 2017).

3.2.1.2. WOVEN FABRIC

The woven fabric used was a 125 g/m^2 plain weave (24 ends x 17 picks/cm) made from open-end yarns of 100% unmercerised cotton. The linear density of the warp yarns was 30 tex, and that of the weft yarns 27 tex. Open-end yarns were selected for the woven fabric, since they have a more open structure (Iyer and Shenai: 1991) and better water absorption than ring-spun yarns (Hari and Shankaranarayanan: 1984) hence their dye uptake could be expected to be higher than that of ring-spun yarns (Iyer and Shenai: 1991), with their shade being deeper but slightly duller than those of ring-spun yarns (Chavan: 1981), with a microscopic view of the woven fabric indicated in Figure 3.3.

Figure 3.3 Woven Fabric (Durban University of Technology: 2017).

3.2.2. Sampling

For each trial, approximately 5 woven and 5 knitted garments were dyed simultaneously in the same dyebath. After each trial was conducted, every dyed garment was labelled as per the varied parameter and fabric quality, with a numerical value given for the garment, for example C1-K-3; indicated Cationisation trial 1, knitted fabric, garment number 3. A random sample, for the woven and knitted garments were selected for testing. The randomly selected woven and knitted garments were used for all 3 tests, firstly for colour strength, thereafter the wash fastness test and lastly for wet and dry rub fastness test.

3.2.3. Auxiliaries and Pigments

Table 3.3. provides a breakdown of the auxiliaries and pigments used in this research, as well as their names, the company they were sourced from and a brief description of the product.

Table 3.3 List of Auxiliaries and Pigments.

Auxiliaries	Name/s	Source	Description
Scouring	Lanaryl RK	Dyecom	Non-ionic detergent
Cationizing Agents	Eco PreDye PD	Dyecom	Cationic water-soluble polymer
	Colofix FRD	M & S Color Chem	Cationic polymeric, quaternary ammonium compound
Anti-Foam	Sera Foam M-SI Conc	Dyecom	Non-ionic silicone emulsion
Pigments	Ecodye Navy Blue CRDG	Dyecom	Organic pigment containing anionic and non-ionic surfactants
	Octamine Navy FT-SH	M & S Color Chem	Inorganic pigment
Binder / Fixer	Helizarin Binder ET ECO	M & S Color Chem	Acrylate based
	Helizarin Fixing Agent LF		Methoxylated melamine, polycondensate
Soaping	Sera Fil BCN	DyStar	Phosphonate, alcohol ethoxylate. Low-foaming, peroxide stabiliser with wetting, washing and sequestering properties
	Dekol AA-120	M & S Color Chem	Sodium salt of a low molecular polyacrylic acid
Softeners	Lava Soft EPH conc.	Dystar	Cationic quaternary compound
	Colosil MAS - H	M & S Color Chem	Non-ionic, micro amino silicone softener
pH Agent	Acetic Acid	Protea Chemicals	

3.2.4. Equipment

All the equipment used in this study were as used by Spectrum Textiles for the pigment dyeing of their cotton garments.

3.2.4.1. ROTATING DRUM MACHINE

A rotating drum type machine, the Lavamat 64 SL (Figure 3.4), which has a capacity of 1.5 kg, was used to conduct all pigment dyeing trials.

(b)

(a)

Figure 3.4 Lavamat 64 SL Rotating Drum Garment Dyeing Machine, (a) Exterior and (b) Interior (Spectrum Textiles: 2017).

3.2.4.2. FINISHING MACHINE

Hydro-extraction of the dyed garments was achieved using a high speed household unit, called Spindel, as shown in Figure 3.5. The machine was run for approximately 2 minutes, to remove excess water before transferring the dyed garments, for drying, to an Electrolux household rotary tumble drier, as depicted in Figure 3.6.

Figure 3.5 Spindel, Hydro-Extraction Unit (Spectrum Textiles: 2017).

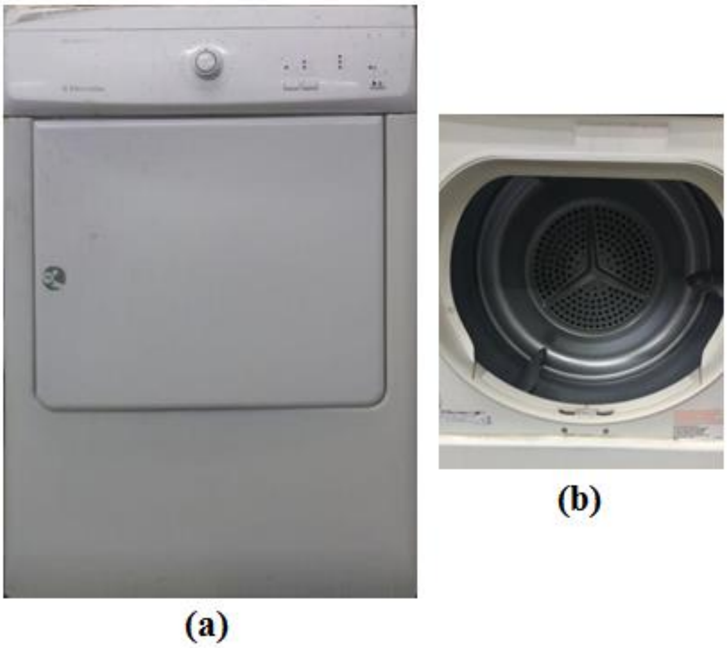


Figure 3.6 Electrolux Household Rotary Tumble Drier with (a) Exterior and (b) Interior (Spectrum Textiles: 2017).

3.2.4.3. WEIGHING BALANCE

Prior to dyeing, the fabric weighing, at Spectrum Textiles, was carried out using the Digi DI-20 scale; while pigments and auxiliaries were weighed using the AND EK-610i scale.

3.2.4.4. pH METER

pH was measured using an EDU TECH pH meter, with calibrations done at the beginning of each week.

3.3. RESEARCH METHODOLOGY

Woven and knitted garments were weighed to ± 1 kg and then pigment dyed in accordance with the requirements for each trial. Approximately 5 woven and 5 knitted garments were pigment dyed simultaneously in the same dyebath for each trial, with a total of 78 trials being conducted for both the Blue pigments (39 each) provided by the two different dyestuff suppliers. Another 39 trials each were carried out for the 2 Blue pigments, however in this instance the pigment dyeing process route was changed. A total sum of 156 trials were therefore carried out using the Lavamat 64 SL rotating drum garment dyeing machine.

3.4. PIGMENT DYEING EXPERIMENTAL PLAN

Six parameters were varied for each trial, with the levels of each parameter expressed in the pigment dyeing experimental plan represented in Table 3.4, which shows a total of 9 trials required for each parameter, with trials 1, 5 and 9 being common for all the parameters. These 3 common trials were only conducted for the 1st parameter, namely Cationisation, and not repeated for the remainder of the trials. K/S, wash fastness and dry and wet rub fastness results, obtained for these 3 common trials, were carried forward throughout the statistical analyses.

Table 3.4 shows the pigment dyeing experimental plan that was followed for the two process routes with the same variables used for each of the two dyestuff suppliers, however with the second process route, the only change being effected was that the binder/fixer was applied prior to the pigment, and not after, as indicated in Table 3.4.

Table 3.4 Pigment Dyeing Experimental Plan (Red colour signifying common trials).

Parameters Investigated	Cationisation (%)	pH	Pigment (%)	Temp (˚C)	Binder (%)	MLR	Trial No.
Cationisation	4	3	5	60	3	1:8	1
	4	5	7	70	5	1:15	2
	4	6	9	80	7	1:20	3
	6	3	5	60	3	1:8	4
	6	5	7	70	5	1:15	5
	6	6	9	80	7	1:20	6
	8	3	5	60	3	1:8	7
	8	5	7	70	5	1:15	8
	8	6	9	80	7	1:20	9
pH	4	3	5	60	3	1:8	1
	6	3	7	70	5	1:15	2
	8	3	9	80	7	1:20	3
	4	5	5	60	3	1:8	4
	6	5	7	70	5	1:15	5
	8	5	9	80	7	1:20	6
	4	6	5	60	3	1:8	7
	6	6	7	70	5	1:15	8
	8	6	9	80	7	1:20	9
Pigment	4	3	5	60	3	1:8	1
	6	5	5	70	5	1:15	2
	8	6	5	80	7	1:20	3
	4	3	7	60	3	1:8	4
	6	5	7	70	5	1:15	5
	8	6	7	80	7	1:20	6
	4	3	9	60	3	1:8	7
	6	5	9	70	5	1:15	8
	8	6	9	80	7	1:20	9
Binder	4	3	5	60	3	1:8	1
	6	5	7	70	3	1:15	2
	8	6	9	80	3	1:20	3
	4	3	5	60	5	1:8	4
	6	5	7	70	5	1:15	5
	8	6	9	80	5	1:20	6
	4	3	5	60	7	1:8	7
	6	5	7	70	7	1:15	8
	8	6	9	80	7	1:20	9
Temperature	4	3	5	60	3	1:8	1
	6	5	7	60	5	1:15	2
	8	6	9	60	7	1:20	3
	4	3	5	70	3	1:8	4
	6	5	7	70	5	1:15	5
	8	6	9	70	7	1:20	6
	4	3	5	80	3	1:8	7
	6	5	7	80	5	1:15	8
	8	6	9	80	7	1:20	9
Material-to-Liquor Ratio	4	3	5	60	3	1:8	1
	6	5	7	70	5	1:8	2
	8	6	9	80	7	1:8	3
	4	3	5	60	3	1:15	4
	6	5	7	70	5	1:15	5
	8	6	9	80	7	1:15	6
	4	3	5	60	3	1:20	7
	6	5	7	70	5	1:20	8
	8	6	9	80	7	1:20	9

3.5. LIMITING CONDITIONS

Each pigment dyeing trial takes approximately 6 hours to complete. Hence only one trial per day could be conducted; depending on machine availability, as the dyeing machine was also used for daily lab dyeings for the company. In the light of this, a **full factorial** experimental design, to determine the effects of the 6 varied parameters on K/S, wash fastness and wet and dry fastness to rubbing, could not be conducted in the time frame required to finish this MSc as it would have taken over 5 years for the dyeings to be completed, with additional time needed for testing and analysing. Sourcing of sufficient fabric for a **full factorial** experimental design would also have been quite daunting as each trial requires ± 1 kg of garments. A total of ± 730 kg of fabric would have been required, not taking into account additional fabric required for repeat dyeings, should there be human error. Therefore, in the light of the foregoing, only a **partial factorial** experimental design, in terms of the effects of the varied parameters on K/S, and wet fastness, could be conducted.

3.6. LOCATION OF TRIALS

All pigment dyeing trials were conducted at Spectrum Textiles (Pty) Ltd, which is a medium sized garment dyeing company, based in Durban. The company does not have its own laboratory, and the dyehouse personnel rely on customer feedback, in terms of pass or fail ratings of colour fastness and colour strength. For this research, the wash fastness and rub fastness tests for the pigment dyed garments were performed at the Textile Technology Laboratory at the Durban University of Technology, using a James H. Heal Washwheel and an AATCC Crockmeter. The Spectrophotometry tests, to determine colour strength, was conducted in Hammarsdale at the Advanced Textile Services Laboratory (ATS) at Gelvenor Consolidated Fabrics (Pty) Ltd using a DataColor SF600+ spectrophotometer.

3.7. PROCESS OPTIMIZATION

3.7.1. Cationisation Concentration

Various studies have been carried out since 2005 on the cationisation of cotton fabrics as well as garments, in relation to pigment dyeing (Fang *et al*: 2005, Patra *et al*: 2006, Ristić and Ristić: 2012, Kumar *et al*: 2013, Wu and Zhang: 2013, Choudhury: 2014, Saha *et al*: 2015). These studies have used cationising concentrations from 2% to 12% (owf), with good results on colour strength being reported for cationising concentrations between about 6 and 8%, when employing differing levels of pH, pigment concentrations, time, temperature and MLR. The results of these studies have informed the selection of variables and their levels in the present study. In particular, the concentration of cationising agent was fixed at 4, 6 and 8 % (owf), respectively while the pH, temperature and time used for the cationisation process were according to the recommendations of the dyestuff suppliers.

3.7.2. pH Level

In their research, Kumar *et al* (2013), used pH of 2, 4, 5 and 6 on cationised cotton fabric, and concluded that a better pigment uptake occurred at pH of 5. These results were, however, based on beaker dyeings, and it was therefore decided that, in the present study, pH levels of 3, 5 and 6 would be used for both the pigment and binder.

3.7.3. Pigment Concentration

Broadbent (2001), stated that "with increasing amounts of absorbed dyes, the colour of the goods become deeper, but duller with a slight change in hue. Deep shades have lower fastness to wet treatments and rubbing than pale shades". This statement also holds true for pigments as reported by other researchers (Kumar *et al*: 2013, Wu and Zhang: 2013, Saha *et al*: 2015). Research work carried out on cotton fabrics by Patra *et al* (2006) and Kumar *et al* (2013), as well as Saha *et al* (2015) on cotton garments, used pigment concentrations of 1-3%, 4% and 5%, respectively, with the 5% results still showing unevenness. Cotton Incorporated (2000) stated that a Red pigment concentration of 9%, resulted in a high degree of staining of the equipment. Taking these studies into account, it was decided to cover Blue pigment concentrations (owf) of 5, 7 and 9 % for this research.

3.7.4. Binder / Fixer Concentration

In research on the pigment dyeing of cotton fabrics, Patra *et al* (2006) used binder concentrations (owf) at 3, 5, 7 and 10%, with 5% providing the best results. Saha *et al* (2015) used 2g/l of fixer on cotton garments, at a pigment concentration of 5%, with the results still showing unevenness. In the light of the above, concentration of binder/fixer at levels of 3, 5 and 7 % (owf) were selected. Higher concentrations would not be cost effective and would render the handle of the garment unacceptably harsh.

3.7.5. Temperature Level

Broadbent (2001) stated that "longer dyeing times at elevated temperatures usually result in better colour levelness". Research on pigment dyeing of cotton fabrics, by both Fang *et al* (2005) and Patra *et al* (2006), involved temperatures ranging from room temperature to 80°C, and 50° - 100°C (with 10° increments), respectively. Fang *et al* (2005) studied the effects of temperature on cationisation, and concluded that temperatures higher than 80°C yielded a lower pigment uptake. Patra *et al* (2006) concluded that 60°C for the Blue pigment, produced the best dye uptake. Wu and Zhang (2013) also conducted research on the effects of temperature, ranging from 50° - 100°C. These trials were, however, on the pigment dyeing of Cotton/Polyester fabrics. They concluded that K/S increased with an increase in temperature from 50° to 70°C, after which it decreased with further increase in temperature (above 70°C). Based on the foregoing studies, temperatures of 60, 70 and 80°C were selected for this study.

3.7.6. Material-to-Liquor Ratio (MLR)

Broadbent (2001) stated that "lower liquor ratios minimise the consumption of energy for heating the water and that an increase in the liquor ratio causes a decrease in the degree of exhaustion and therefore a decrease in the depth of colour of the dyeing". Kumar *et al* (2013) agreed with this statement, mentioning that "lower liquor ratio shifts the equilibrium in favour of the pigment on the fibre, with the equilibrium being reached more rapidly".

Material-to-liquor ratios, for rotating drum machines, of 1:10 or lower was suggested by Park and Shore (2004), with additional ratios of 1:3 and 1:8 for 50 – 150 kg fabric. Ingamells (1993) also suggested material-to-liquor ratios ranging from 1:5 up to 1:30 or higher, for batchwise dyeing machines. Fang *et al* (2005) and Patra *et al* (2006) also conducted their research, using a short material-to-liquor ratio of 1:20. In light of the above, it was decided that the material-to-liquor ratio for this research would be 1:8, 1:15 and 1:20.

3.8. TESTING OF DYED FABRICS

After the pigment dyeing and finishing of the garment, physical testing needs to take place to ensure that the fabric has met the required standards for the intended end use. The following sections discusses the methodology and standards for the testing of pigment dyed garments.

In this study the dyed fabrics were analysed in terms of colour strength, colour fastness to washing and, dry and wet rubbing. There are various standards available for the testing of textiles, such as ISO (International Standards Organization), AATCC (American Association of Textile Chemists and Colourists) and B.S. (British Standards) (Cao: 2013). South African textile industries also make use of standards, such as the South African National Standards (SANS) and Marks and Spencer (M&S). The following section discusses the various test methods employed in this research.

3.8.1. Physical Testing

3.8.1.1. COLOUR FASTNESS

A means of assessing the colour fastness properties of a fabric is by assessing the level of staining of an adjacent white sample alongside the simultaneous fading of the dyed specimen under test (Jaeckel: 1980, Saville: 1990) and are assessed using the Grey Scale for Staining and the Grey Scale for Colour Change (Chakraborty: 2014). The grey scales for change in colour, and staining, are graded from 1 to 5, in nine different grades (steps) of fading or staining, namely 5, 4-5, 4, 3-4, 3, 2-3, 2, 1-2 and 1, where 1 stands for poor and 5 for excellent colour fastness, respectively (Jaeckel: 1980). Below is an indication of an acceptable rating (Chakraborty: 2014):

- Colour change in shade – Grade 4 (good result)
- Colour staining in cotton – Grade 4/5 (good result)

Contrary to the acceptable rating above, the clients of Spectrum Textiles accept wet rub fastness ratings of 3 or higher.

3.8.1.1.1. Colour Fastness to Rubbing: Test Method C8 (M&S: 2004)

This particular test method was chosen, due to its limited requirements, such as crocking squares, distilled water and a viewing box with D65 illuminant. Further to this, this test method is predominantly used by a leading textile testing company in Hammarsdale, namely ATS Laboratory, and is also accepted internationally.

- Purpose:

This test method is designed to determine the degree of colour transfer or staining, caused by rubbing, and is applicable to textiles made from all fibres, in the form of yarn or fabric, and whether dyed or printed (M&S: 2004).

- Requirements:

Pigment dyed garments are tested on both sides of the body fabrics for both dry and wet tests. For this test, the AATCC Crockmeter, as illustrated in Figure 3.7, was used with the Cotton Lawn being sourced from James H Heals.

The crockmeter, with a rubbing track of 105 mm ± 5 mm long, is fixed with emery paper, of grades between 180 and 320, to improve specimen holding and reduce specimen movement.

The peg, which is flat and circular with a diameter of 16 mm, exerts a downward force of 9.0 N ± 0.2 N. The test specimen need not be prepared, but must at least be 250 mm long in the direction of test and at least 50 mm wide. The Cotton Lawn, either manufactured by The Society of Dyers and Colourists (SDC) or James H Heal, should be 50 mm x 50 mm.

Figure 3.7 Crockmeter (AATCC: 2005)

- Method:

The specimen is mounted on the rubbing area of the test base and tensioned using the device provided, which is a steel plate, with a cut out of 135 mm x 25 mm, for the specimen to be tested.

  - Dry Rub

The cotton lawn is placed over the end of the peg of the crockmeter and held taut by the spring clip. The peg is rested on the test specimen, ensuring that the spring clip is not in contact with the test specimen. The peg is rubbed to and fro along the test specimen at the rate of 10 complete cycles (20 strokes) in 10 ± 1 seconds.

  - Wet Rub

The cotton lawn is thoroughly wet out, in a petri dish containing distilled water, and then removed from the petri dish and folded twice, into quarters, and gently squeezed between the thumb and forefinger, avoiding the folds. The cotton lawn is then opened out and laid flat across the back of the hand and gently patted to remove any excess moisture. The test is then carried out, as for the dry rub test, using a different test specimen. The cotton lawn is allowed to dry at a temperature, not exceeding 60°C.

- Evaluation and Reporting:

After the test, the cotton lawn was mounted on a white card and assessed by means of the Grey Scale for Staining by comparison with the unstained areas of the cotton lawn. The assessment was done at 45°, in a light box, under D65 light. The staining results of the cotton lawn for the dry and wet rub tests were reported separately. All dyed fabrics and cotton lawn were assessed by means of the Instrumental Colour Systems Ltd Multi-light box, using D65 illuminant, in the Textile Technology laboratory at the Durban University of Technology.

3.8.1.1.2. Colour Fastness to Domestic Washing: SANS 11166:2006 (South African National Standards: 2006)

This particular test method was used, as it primarily requires domestic washing powder and distilled water at lower temperature, with no additional chemicals; thus making it eco-friendly. Once again, this test method is predominantly used by ATS Laboratory.

- Scope and Principle:

This standard specifies a method of determining the effect of domestic washing procedures on the colour fastness of a textile.

A test piece of the textile to be tested, is combined with a multifibre adjacent fabric to form a composite test specimen of given dimensions. The composite test specimen is washed, rinsed and dried under specific conditions and then assessed for any change in colour of the test piece and any staining of the adjacent fabric.

- Requirements:

A mechanical wash-wheel type washing device that has individual containers and is capable of maintaining the contents of the containers at the required temperature. In the present study, all the dyed fabrics were tested, for wash fastness to domestic laundering, using the James H Heal Washwheel with 8 containers, as depicted in Figure 3.8.

Figure 3.8 James H Heal Washwheel (Durban University of Technology: 2017).

- Detergent solution that contains, dissolved in each litre of distilled water, 5g of commercial detergent (low foam for use in automatic and non-automatic domestic washing machines). For this test, Skip automatic washing powder was used and preheated to a temperature of 40°C.

- Multifibre adjacent fabric of approximately 100 mm x 40 mm, of type DW was used for the colour fastness to domestic washing test. The multifibre adjacent fabric, which consisted of diacetate, bleached cotton, polyamide, polyester, acrylic and worsted wool, was purchased from Dutest Agencies, a supplier of James H Heal products.

- Calibrated balance

  A calibrated balance, Denver Instruments, model XL 410 (Figure 3.9), was used to weigh the test samples and auxiliaries in the Textile Technology Laboratory at the Durban University of Technology.

Figure 3.9 Denver Instruments Scale Model XL 410 (Durban University of Technology: 2017).

- Light / Viewing Box

All the dyed fabrics, and multifibre adjacent fabrics, were assessed by means of the Instrumental Colour Systems Ltd Multi-light box, using D65 illuminant (Figure 3.10.), in the Textile Technology Laboratory at the Durban University of Technology.

Figure 3.10 Instrumental Colour Systems Ltd Multi-light Box, using D65 Illuminant (Durban University of Technology: 2017).

- <u>Method</u>:

The wash wheel was preheated to a temperature of 40 ± 2°C, and the detergent solution prepared according to the requirements. A test specimen, of approximately 100 mm x 40 mm, was cut and attached to the multifibre adjacent fabric by sewing along one of the shorter sides, with the multifibre fabric next to the face of the test specimen. The composite test specimen was weighed and the required detergent solution measured out to give a liquor ratio of 50:1 (50 ml detergent solution per 1 g of the composite test specimen). The composite specimen and required detergent solution were placed in a container and clamped in the wash wheel. The machine was operated to agitate the composite test specimen in the container for 30 minutes.

The composite test specimen was removed from the container, and rinsed well in distilled water, and then again in cold running tap water for 10 minutes. The excess water was then squeezed out and the test piece separated from the adjacent fabric. The fabrics were allowed to dry, separately, at a temperature not exceeding 60°C.

- Evaluation:

The changes in colour of the test specimen and the staining of the multifibre adjacent fabric were assessed using the Grey Scales (Figures 3.11 and 3.12.) in a light box under D65 illuminant, using the suppressor glass filter of the fluorescence suppressor kit.

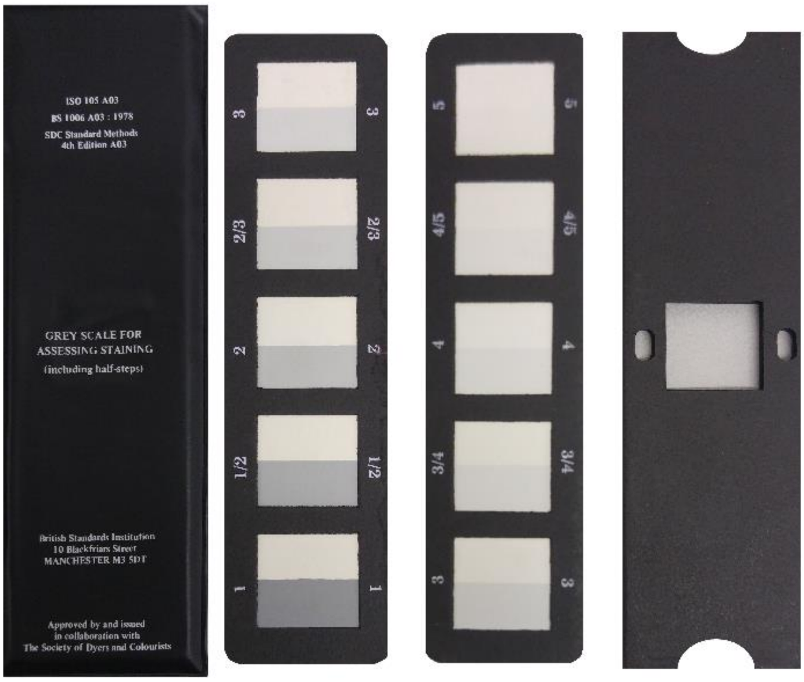


Figure 3.11 SDC Grey Scale for Assessment of Staining (Durban University of Technology: 2017).

Figure 3.12 SDC Grey Scale for Assessment of Change in Colour (Durban University of Technology: 2017).

3.8.1.2. <u>COLOUR STRENGTH</u>

The DataColor SF 600+ spectrophotometer (Figure 3.13.) at ATS Laboratory in Hammarsdale, was used to measure the colour strength of the dyed garments. The calibration of this machine was carried out by the supplier at 6 monthly intervals as well as daily by the operator, prior to use.

Figure 3.13 DataColor SF 600+ Spectrophotometer (DataColor 600 User's Guide: 2007).

This model of spectrophotometer gave reflectances at every 10 nm, between 400 and 700 nm, with a viewing geometry of D/10°. The light source was a pulsed xenon flash lamp, filtered to provide D65 illumination, including a UV component. Aperture sizes ranged from 6.6 mm to 30 mm, with the Large Area View (LAV) of 30 mm being used for all measurements of the dyed garments (Figure 3.14.).

Figure 3.14 Aperture Sizes ranging from 6.6 mm to 30 mm (DataColor 600 User's Guide: 2007).

The colour strength (K/S) for both knitted and woven garments were calculated, using the reflectance values obtained from the spectrophotometer. One knitted and one woven sample was, respectively, tested at 4 different points, with the average result taken for each sample. The K/S values of the tested dyed garments, based on the reflection spectra at a wavelength of 450 nm, were determined, using the Kubelka Munk equation:

$$K/S_{\lambda} = \frac{(1 - R_{\infty})^2}{2R_{\infty}}$$

3.9. PIGMENT DYEING PROCESS ROUTES

3.9.1. Process Route 1

This process route requires scouring, cationising, pigmenting, binding/fixing, softening, spin drying and finally drying.

A detailed description of dyeing Process route 1 is given below:

1) Scour (Lanaryl RK – Dyecom)

- Load machine with ± 1kg fabric (weft knitted and woven)
- Fill with water (Liquor Ratio of 1:8, 1:15 or 1:20 – as required)
- Adjust pH to 6
- Add 1 g/ℓ detergent
- Raise temperature to 70°C
- Run for 10 minutes
- Drain bath
- Fill with water (Liquor Ratio of 1:8, 1:15 or 1:20 – as required)
- Rinse for 3 minutes in cold water
- Drain

2) Cationising (Eco PreDye PD – Dyecom or Colofix FRD – M & S Color Chem)

- Fill with water (Liquor Ratio of 1:8, 1:15 or 1:20 – as required)
- Adjust pH to 4.5 – 5.0
- Run for 5 minutes
- Add cationising agent at required concentration (4, 6 or 8% owf - as required), over 5 minutes
- Run for 10 minutes cold
- Raise temperature (2°C per minute) to 50°C
- Run for 20 minutes
- Drain

3) Pigmentation (Sera Foam – DyStar & Pigments – Dyecom or M & S Color Chem)

- Fill with water (Liquor Ratio of 1:8, 1:15 or 1:20 – as required)
- Adjust pH level (3, 5 or 6 – as required)
- Run for 5 minutes
- Add 1 g/ℓ Anti-foam (Sera Foam M-SI Conc)
- Add pigment at required concentration (5, 7 or 9% owf - as required), over 15 minutes at 3 minute intervals (5% conc.)
- Run 15 minutes cold
- Raise temperature (2°C per minute) to required temperature (60, 70 or 80°C – as required)
- Run for 10 minutes
- Drain

4) Binder/ Fixer (Helizarin ET ECO or Helizarin Fixing Agent LF – M & S Color Chem)

- Fill with water (Liquor Ratio of 1:8, 1:15 or 1:20 – as required)
- Adjust pH level (3, 5 or 6 – as required)
- Add Binder / Fixer at required concentration (3, 5 or 7% owf - as required), over 10 minutes at 2 minute intervals
- Raise temperature (2°C per minute) to required temperature (60, 70 or 80°C – as required)
- Run for 15 minutes
- Drain

5) Soaping (Sera Fil BCN – DyStar or Dekol AA-120 – M & S Color Chem)

- Fill with water (Liquor Ratio of 1:8, 1:15 or 1:20 – as required)
- Rinse 5 minutes cold
- Drain
- Fill with water (Liquor Ratio of 1:8, 1:15 or 1:20 – as required)
- Add 1 g/ℓ Soaping agent
- Adjust pH to 6.5 – 7.0
- Raise temperature (2°C per minute) to required temperature (60, 70 or 80°C – as required)
- Run for 5 minutes
- Drain
- Fill with water (Liquor Ratio of 1:8, 1:15 or 1:20 – as required)
- Rinse 5 minutes cold
- Drain

6) Softening (Lava Soft – DyStar or Colosil MAS – H – M & S Color Chem)

- Fill with water (Liquor Ratio of 1:8, 1:15 or 1:20 – as required)
- Adjust pH to 5.0 – 5.5
- Add 3% owf softener
- Run for 7 minutes at 30°C for Lava Soft or 20 minutes at 40°C for Colosil
- Drain

7) Spin Dry (Hydroextract)

8) Dry at ± 140°C (Electrolux Household Tumble Dry)

3.9.2. Process Route 2

The second process route was identical to the first, except that the binder/fixer was applied before the pigmentation step. Figure 3.15 illustrates both the first and second process routes.

3.10. CLEANING OF THE DYEING MACHINE

A high staining of the dyeing machine, after a large number of pigment dyeings, necessitated thorough cleaning, with the following procedure being used:

1) Fill bath with water.
2) Add 5 g/l Lanaryl RK. Raise temperature to 90°C and run for 30 minutes.

3) Cool down bath, thereafter drain.
4) Fill bath with water and rinse machine.
5) Drain bath.
6) Fill bath with water and add 5 g/l Serafil BCN and 2 g/l Soda Ash. Raise temperature to 90°C and run for 30 minutes.
7) Drain bath.
8) Fill bath with water and rinse machine.
9) Fill bath with water and add 5 g/l Caustic Soda. Raise temperature to 90°C and add 5 g/l Hydros and run for 30 minutes.
10) Drain bath.
11) Fill bath with water and rinse machine.
12) Drain bath.

3.11. STATISTICAL TREATMENT

The wash fastness, and wet and dry rub fastness results were analysed in terms of the ratings from the Grey Scales for Staining; whereas the K/S results were analysed by comparing the means for each dyeing combination and as a total value for each of the 6 parameters investigated.

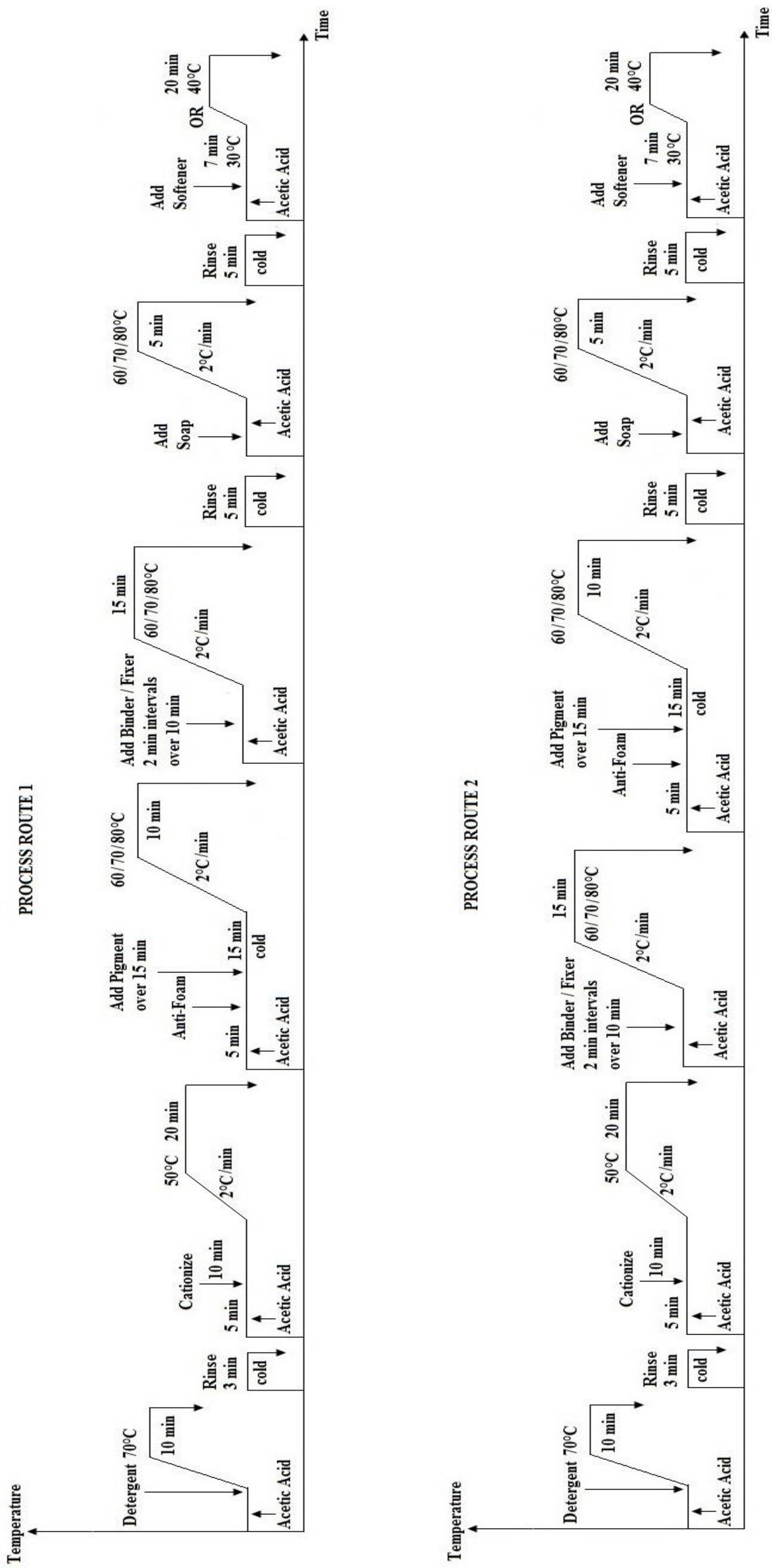


Figure 3.15 Dyeing Process Routes 1 and 2.

Chapter 4: Results and Discussion

4.1. INTRODUCTION

This chapter presents the results and discussion for each parameter and process route studied. Six parameters were systematically investigated, namely Cationisation, pH, Pigment, Temperature, Binder/Fixer and Material-to-Liquor Ratio, as well as two dyeing process routes/sequences, to determine their effects on the K/S, wash fastness and wet and dry rub fastness ratings of both knitted and woven garments. The dyestuffs from two different suppliers were also compared in the process.

4.2. DATA ANALYSIS

The results obtained for colour strength, wash fastness to domestic laundering and wet and dry rub fastness, on the dyed fabrics, were analysed and presented graphically.

4.2.1. Acceptable Industry Grey Scale Ratings for Pigment Dyeing

Apart from obtaining the highest possible K/S, it is also necessary to obtain good fastness levels for the dyeing to be successful. In this regard, the acceptable Grey Scale ratings for pigment dyeing by industry, for the change in colour and staining, are as follows:

- Change in Colour - 4 or higher
- Wash fastness - 4 or higher
- Dry rub fastness - 4 or higher
- Wet rub fastness - 3/4 or higher

Preliminary trials revealed that the addition of the pigment over periodic intervals eliminated the problem of unlevelness as compared to findings obtained by previous works carried out in the literature review when the pigment was added all at once. Therefore all dyeings were carried out with the pigment being added over periodic intervals. In addition, the wash fastness and change in colour, for all parameters, across all dyeing combinations for both dyestuff suppliers, achieved ratings of at least 4, and will therefore not be reported on in the following sections.

However, the sections that follow, discusses the findings of the test results obtained when the dyeing sequences and suppliers were compared, in terms of K/S and dry and wet rub fastness, as indicated in Figure 4.1.

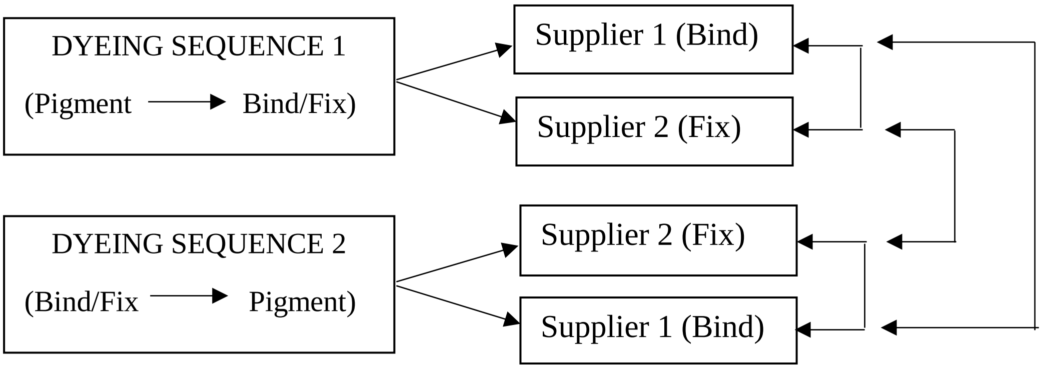


Figure 4.1 Flowchart for the Comparison of the Dyeing Sequences and Dyestuff Suppliers.

The dyeing conditions and results associated with fastness levels of 3/4 and higher are dealt with hereafter, with additional emphasis placed on results that achieved fastness levels of 4 and higher.

The dyeing combinations conducted for this research had 54 trials each, for knitted and woven fabrics, for both dyestuff suppliers, and were analysed to determine the relationship between the 6 parameters (cationisation, pH, pigment, temperature, binder/fixer and MLR) on the outcome of K/S and rub fastness. The dyeing combinations used in this research is given in Table 4.1.

Table 4.1 Dyeing Combinations.

Dyeing Combinations	Cationisation (%)	pH	Pigment (%)	Temp (°C)	Binder/Fixer (%)	MLR
	4, 6 and 8	3, 5 and 6	5, 7 and 9	60, 70 and 80	3, 5 and 7	1:8, 1:15 and 1:20

4.3. COMPARING DYESTUFF SUPPLIERS 1 AND 2

Two dyestuff suppliers underwent the same dyeing conditions for each trial, per parameter investigated, with the results for the knitted and woven fabrics, for both suppliers, being compared in terms of K/S and fastness for the two dyeing sequences. The knitted and woven fabrics were dyed in one bath, wherein dyeing sequence 1 had the pigment being exhausted prior to the exhaustion of the binder/fixer, while for dyeing sequence 2, the fabrics were exhausted with binder/fixer prior to the exhaustion of the pigment. The test analysis of the results, for each parameter, are discussed hereunder, in the following arrangement:

- Suppliers 1 and 2 (Dyeing Sequence 1)

- Suppliers 1 and 2 (Dyeing Sequence 2)
- Supplier 1 (Dyeing Sequence 1 and 2)
- Supplier 2 (Dyeing Sequence 1 and 2)

4.3.1. Effect of Cationisation Concentration

The two dyestuff suppliers were compared to determine the effect of cationisation concentration on the outcome of K/S and fastness, when the cationisation concentrations were increased from 4 to 6 to 8%, while the other 5 parameters (pH, pigment, Temperature, Binder/Fixer and MLR) were kept constant, per dyeing combination. The cationisation concentration trials consisted of three dyeing combinations, with 3 trials per dyeing combination, and were performed using dyeing sequences 1 and 2. The results from these trials for both suppliers and sequences are discussed in section 4.3.7. The dyeing combinations used in the cationisation concentration trials are given in Table 4.2, with the results presented graphically.

Table 4.2 Dyeing Combinations for the Cationisation Concentration Trials.

	Cationisation Concentration Trials						
	Cationisation (%)	**pH**	**Pigment (%)**	**Temp (°C)**	**Binder/ Fixer (%)**	**MLR**	**Trial No.**
Combination 1	4	3	5	60	3	1:8	1
	6	3	5	60	3	1:8	4
	8	3	5	60	3	1:8	7
Combination 2	4	5	7	70	5	1:15	2
	6	5	7	70	5	1:15	5
	8	5	7	70	5	1:15	8
Combination 3	4	6	9	80	7	1:20	3
	6	6	9	80	7	1:20	6
	8	6	9	80	7	1:20	9

4.3.1.1. SUPPLIERS 1 AND 2 (DYEING SEQUENCE 1)

This dyeing sequence had the knitted and woven fabrics dyed simultaneously in one bath. The fabrics were firstly cationised, followed by exhaustion of the pigment then the binder/fixer and finally softened.

The results in terms of K/S, for both suppliers, for the knitted and woven fabrics, for the 3 dyeing combinations, are represented graphically. In addition, the results for wash fastness, and wet and dry rub fastness, including results for the face and back of the fabric, as per the M & S colour fastness to rubbing (Test Method C8: 2004) requirement for pigments, are shown. All test results for the knitted and woven fabric, will be reported on separately due to the difference in yarn and fabric type (construction) and fabric weight.

4.3.1.1.1. Knitted Fabric Results

The K/S for both dyestuff suppliers, for dyeing sequence 1, is represented in Figure 4.2, which clearly shows that the K/S for Supplier 2 is far higher than that for Supplier 1. Supplier 1 shows a decrease in K/S at 4 and 8% cationisation, as the levels of pH, pigment, temperature, binder and MLR are increased, while Supplier 2 exhibits the same trend for all levels of cationisation. Furthermore, dyestuff Supplier 1 also shows a decrease in K/S for dyeing combinations 1 and 2, as the cationisation level increases from 4 to 6 to 8%. Supplier 2, however, only shows an increase in K/S for dyeing combination 1, as the cationisation level increases from 4 to 6 to 8%.

Based on the accepted pass ratings of 3/4 by the textile industry, the ideal dyeing combination/s, for the knitted fabric, was selected from Table 4.3 which showed that Supplier 1 achieved pass ratings at 6 and 8% cationisation for dyeing combination 2, and at 4 and 8% cationisation for dyeing combination 3. Supplier 2, which shows a higher K/S than that for Supplier 1, did not achieve acceptable pass ratings for all cationisation dyeing combinations, with Figure 4.3 showing the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, only dyestuff Supplier 1 passed in terms of all the fastness criteria. Nevertheless, the corresponding K/S values achieved are relatively low.

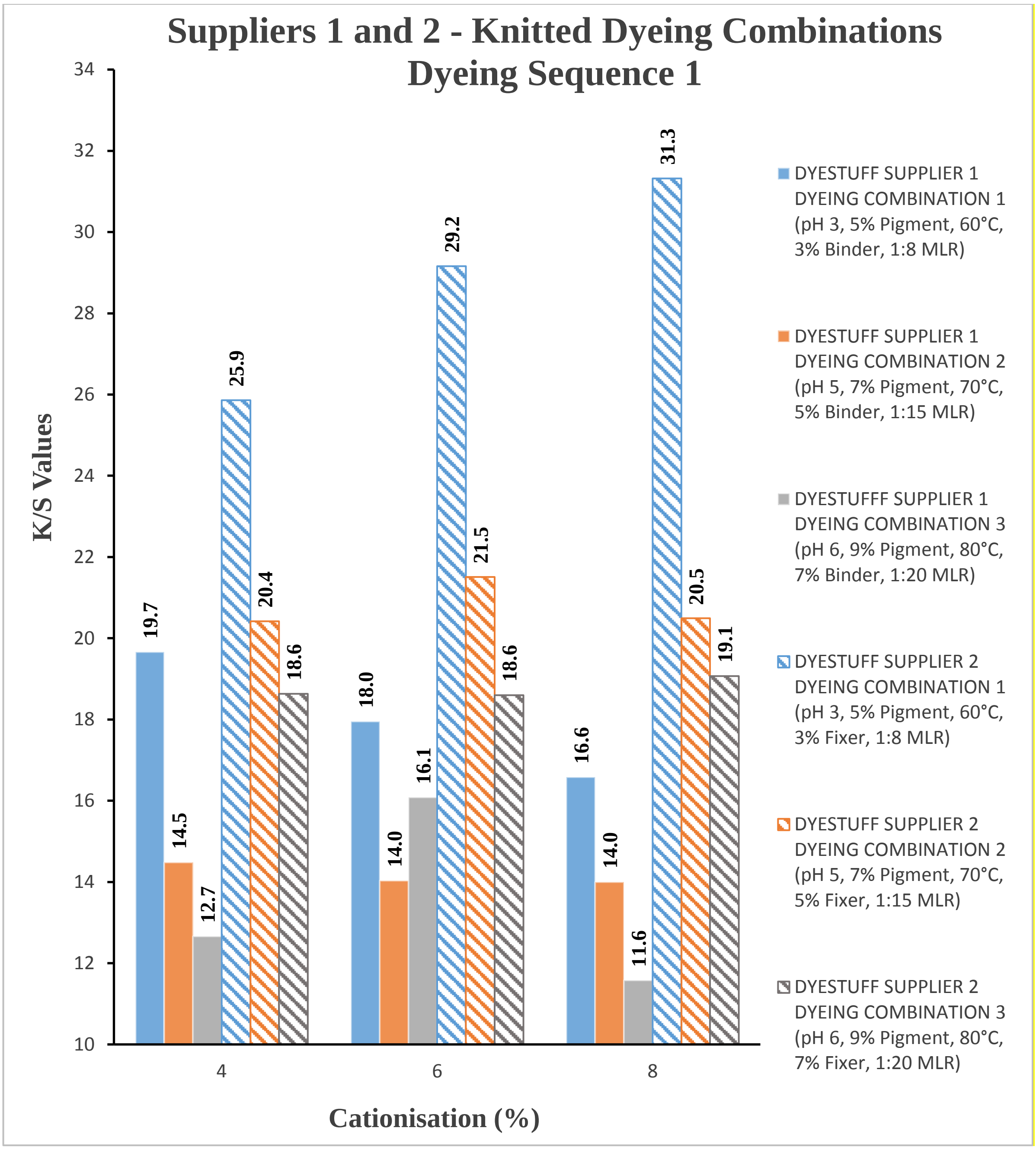


Figure 4.2 Effect of Cationisation Concentration (%) on K/S for the Dyeing Combinations for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

Table 4.3 Knitted Test Results for Cationisation Concentration Trials for Dyeing Sequence 1, Suppliers 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
Cationisation Trials:							KNITTED										Dyeing Combination Averages	Total Cationisation Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	19.7	4/5	3/4	4/5	3	3/4	2/3	2/3	2	2/3	18.1	
	6	3	5	60	3	1:8	18.0	5	4/5	4/5	4/5	4/5	3	3	3	3		
	8	3	5	60	3	1:8	16.6	5	4/5	4/5	4/5	4/5	2	2/3	2/3	3		
2	4	5	7	70	5	1:15	14.5	4/5	4/5	4/5	4/5	4/5	3	3	3	3	14.2	15.2
	6	5	7	70	5	1:15	14.0	5	4/5	4/5	4/5	4/5	4	3/4	4	4		
	8	5	7	70	5	1:15	14.0	5	4/5	4/5	4/5	4/5	3/4	4	4	4		
3	4	6	9	80	7	1:20	12.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4	13.4	
	6	6	9	80	7	1:20	16.1	5	4/5	4/5	4/5	4/5	2/3	2	2	2		
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4		

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
Cationisation Trials:							KNITTED										Dyeing Combination Averages	Total Cationisation Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.9	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3	28.8	
	6	3	5	60	3	1:8	29.2	5	4/5	5	5	5	3	3	3	3		
	8	3	5	60	3	1:8	31.3	5	5	5	5	5	4	2/3	3	3		
2	4	5	7	70	5	1:15	20.4	5	5	5	5	4/5	4	2/3	3	3	20.8	22.4
	6	5	7	70	5	1:15	21.5	5	4/5	5	5	4/5	3/4	3	3	3		
	8	5	7	70	5	1:15	20.5	5	5	5	5	5	3	2/3	2/3	3		
3	4	6	9	80	7	1:20	18.6	5	4/5	4/5	5	4/5	2/3	2/3	2/3	3	18.8	
	6	6	9	80	7	1:20	18.6	5	4/5	4/5	4/5	4/5	2/3	2	2	3		
	8	6	9	80	7	1:20	19.1	5	4/5	4/5	5	5	2/3	2/3	2/3	3		

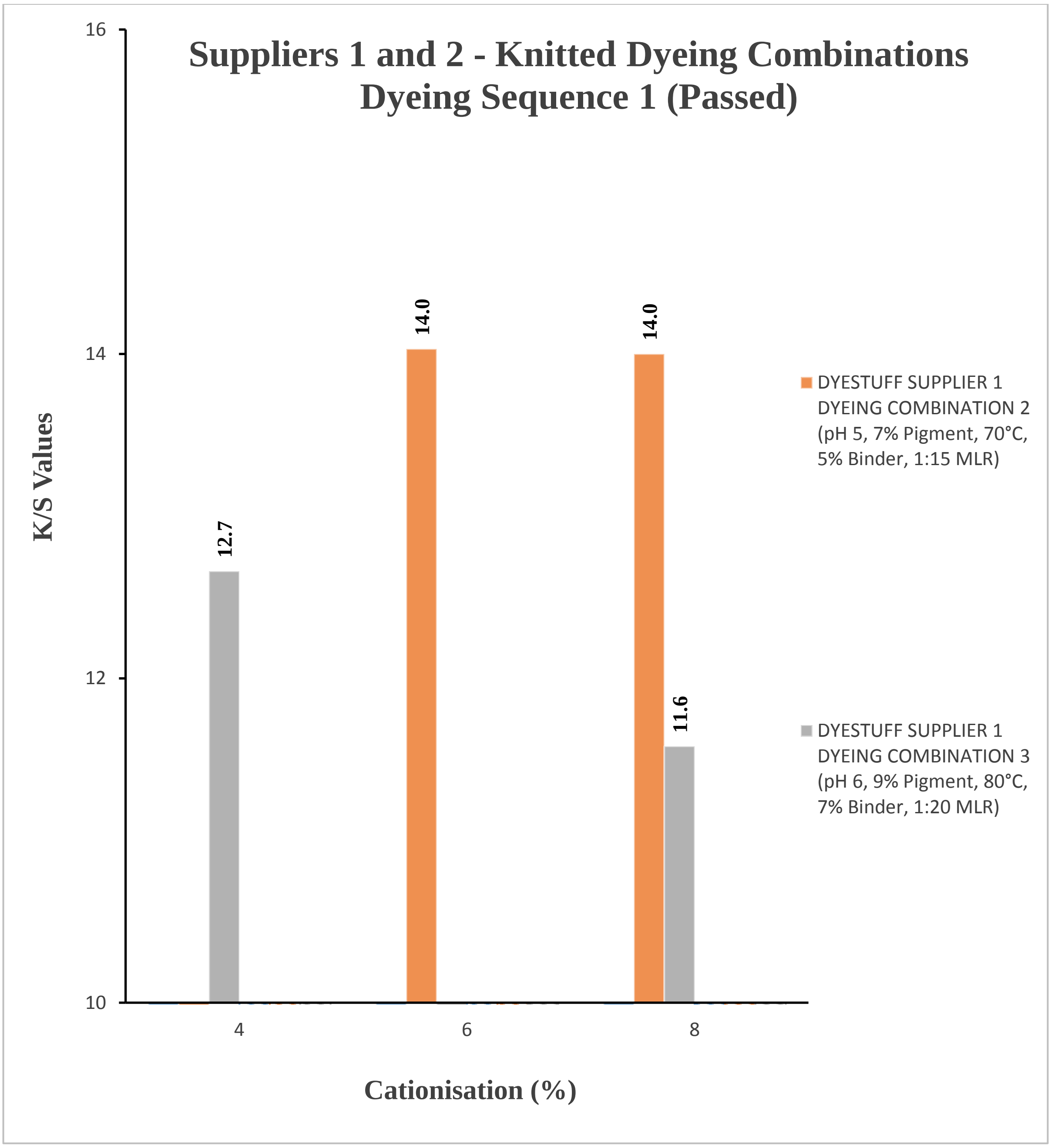


Figure 4.3 Grey Scale Ratings of 3/4 or Higher for Cationisation Concentration Trials for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

4.3.1.1.2. Woven Fabric Results

The K/S for both suppliers, for dyeing sequence 1, is represented in Figure 4.4, and shows that the K/S for the woven fabric, for Supplier 2, is greater than that for Supplier 1. The trend, is also identical to that of the cationisation trials for the knitted fabric.

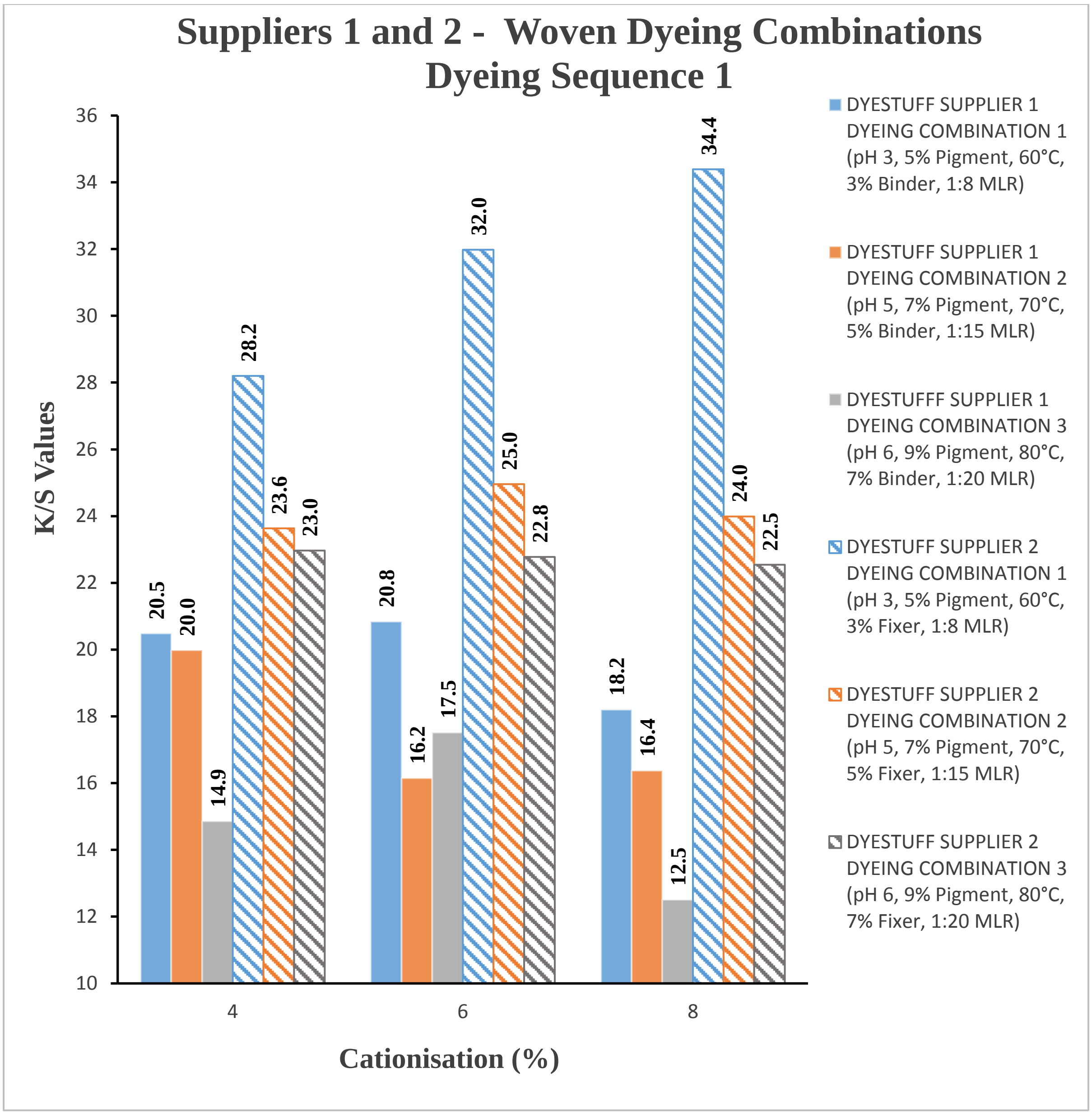


Figure 4.4 Effect of Cationisation Concentration (%) on K/S for the Dyeing Combinations for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

Table 4.4, shows that Supplier 1 achieves pass ratings of 3/4 at all levels of cationisation for dyeing combination 1, at 6 and 8% cationisation for dyeing combination 2, and at 4 and 8% cationisation for dyeing combination 3; whereas Supplier 2, only obtains a pass rating at 6% cationisation for dyeing combination 1. In addition, Figure 4.5 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, dyestuff Supplier 1 passed in terms of all the fastness criteria, with K/S values being relatively low; whereas dyestuff Supplier 2 only achieved a pass at 6% cationisation with a high K/S.

Table 4.4 Woven Test Results for Cationisation Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
Cationisation Trials:							WOVEN										Dyeing	Total
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub		Combination Averages	Cationisation Average
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	20.5	4/5	4/5	4/5	4/5	4/5	4	4/5	3/4	4	19.8	17.1
	6	3	5	60	3	1:8	20.8	4/5	4/5	4/5	4/5	4/5	4	4/5	4	4		
	8	3	5	60	3	1:8	18.2	5	4/5	4	4/5	4	3/4	3/4	3/4	3/4		
2	4	5	7	70	5	1:15	20.0	4/5	4/5	4/5	4/5	4/5	2/3	2/3	3	3/4	17.5	
	6	5	7	70	5	1:15	16.2	5	4/5	4/5	4/5	4/5	4/5	4/5	4	3/4		
	8	5	7	70	5	1:15	16.4	5	4/5	4/5	4/5	4/5	4	4/5	4	4		
3	4	6	9	80	7	1:20	14.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4	15.0	
	6	6	9	80	7	1:20	17.5	4/5	4/5	4/5	4/5	4/5	3/4	4	3	3/4		
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4		
SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
Cationisation Trials:							WOVEN										Dyeing	Total
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub		Combination Averages	Cationisation Average
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	28.2	5	4/5	4/5	5	4/5	3	3	3	2/3	31.5	25.9
	6	3	5	60	3	1:8	32.0	5	5	5	5	5	3/4	3/4	3/4	4		
	8	3	5	60	3	1:8	34.4	5	5	5	5	5	4	3	4	4		
2	4	5	7	70	5	1:15	23.6	5	5	5	5	4/5	4	3	2/3	2/3	24.2	
	6	5	7	70	5	1:15	25.0	5	4/5	4/5	5	4/5	3	3	4	4		
	8	5	7	70	5	1:15	24.0	5	5	5	5	4/5	3/4	3	4	3		
3	4	6	9	80	7	1:20	23.0	5	4/5	4/5	5	4/5	4	4/5	3	2/3	22.8	
	6	6	9	80	7	1:20	22.8	5	5	4/5	5	4/5	4	3	3	3		
	8	6	9	80	7	1:20	22.5	5	5	5	5	4/5	3	4	3/4	3		

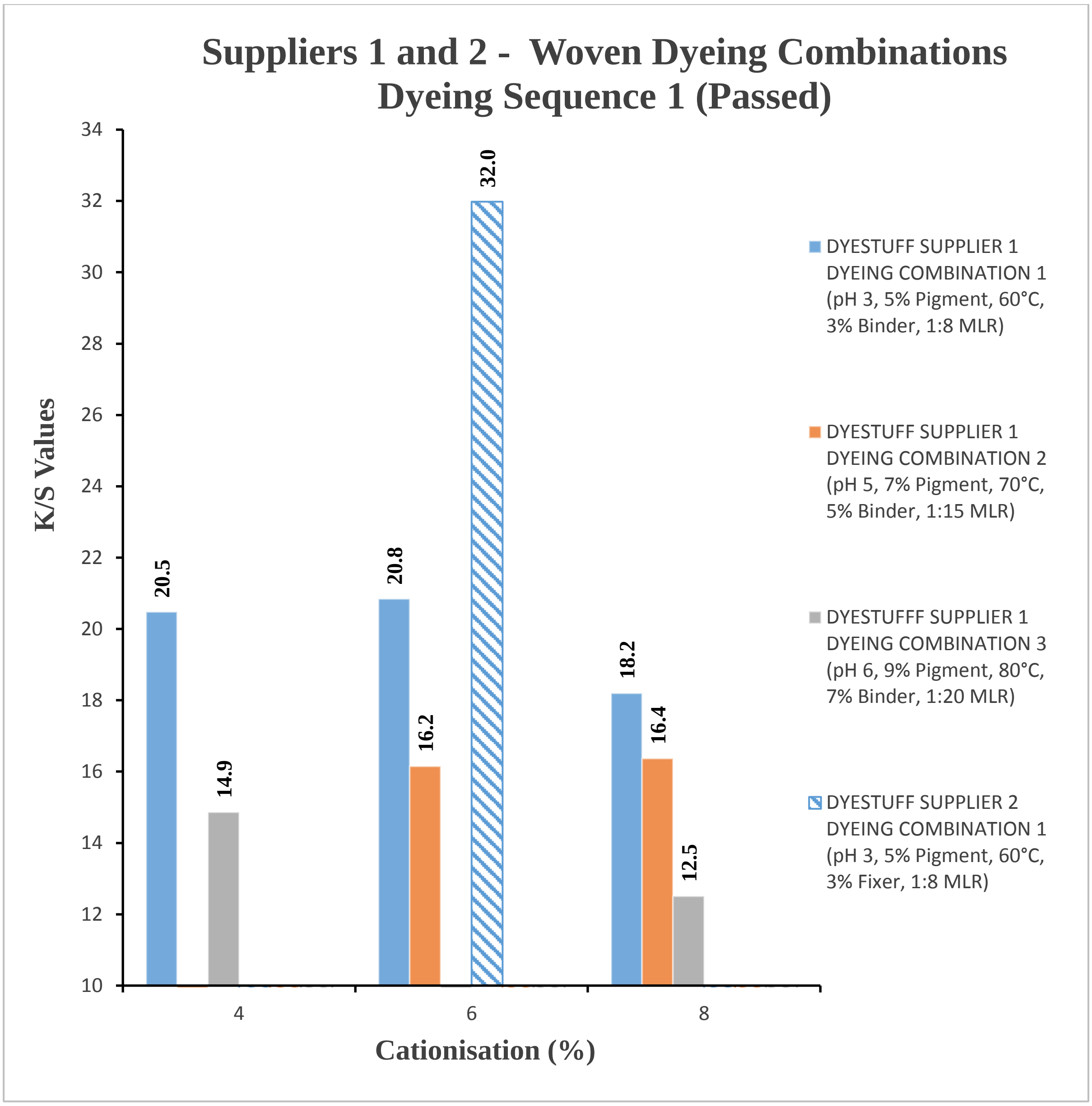


Figure 4.5 Grey Scale Ratings of 3/4 or Higher for Cationisation Concentration Trials for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

4.3.1.2. <u>DISCUSSION</u>

A high K/S was achieved by both dyestuff suppliers, for both fabrics, when lower levels of cationisation, pH, pigment, temperature, binder/fixer and MLR was used. Although Supplier 2 obtained a higher K/S than that for Supplier 1, with a value of 31.3 for the knitted fabric, it failed to achieve acceptable wet rub fastness of 3/4 or above at all cationisation levels compared to that for Supplier 1 which obtained the highest K/S of 14.0 at 6% cationisation for dyeing combination 2, which is relatively low compared to that achieved by Supplier 2. For the woven fabric, dyestuff Supplier 2 obtained a high K/S of 34.4, but again achieved a fail in majority of the wet rub fastness, except at 6% cationisation with a K/S of 32.0 for dyeing combination 1, while Supplier 1 obtained a pass at all levels of cationisation at a lower K/S.

On further inspection, it was established that 2 dyeing combinations for the knitted fabric, and 4 dyeing combinations for the woven fabric, for Supplier 1, achieved pass ratings of 4 or higher in terms of all fastness criteria, with the knitted fabric having the highest K/S of 12.7 at 4% cationisation for dyeing combination 3, while the woven fabric obtained a higher K/S of 20.8 at 6% cationisation for dyeing combination 1.

Although these K/S values are relatively lower than those achieved in the cationisation trials, industry would be more accepting of pigment dyed garments when fastness of 4 or higher are obtained, as indicated in Tables 4.5 and 4.6, which represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, for the knitted and woven fabrics, respectively.

Table 4.5 Ideal Dyeing Combinations for Knitted Fabric for Cationisation Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - SUPPLIER 1																
Cationisation Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
3	4	6	9	80	7	1:20	12.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4

Table 4.6 Ideal Dyeing Combinations for Woven Fabric for Cationisation Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - SUPPLIER 1																
Cationisation Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	6	3	5	60	3	1:8	20.8	4/5	4/5	4/5	4/5	4/5	4	4/5	4	4
2	8	5	7	70	5	1:15	16.4	5	4/5	4/5	4/5	4/5	4	4/5	4	4
3	4	6	9	80	7	1:20	14.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4

It is therefore recommended that a cationisation concentration of 4% for dyeing combination 3 for the knitted fabric be used, while that for the woven fabric should be 6% for dyeing combination 1.

4.3.1.3. <u>SUPPLIERS 1 AND 2 (DYEING SEQUENCE 2)</u>

This dyeing sequence had the knitted and woven fabrics dyed simultaneously in the same bath. The fabrics were firstly cationised, exhausted with the binder/fixer, followed by the exhaustion of the pigment and finally softened.

4.3.1.3.1. Knitted Fabric Results

The K/S for dyeing sequence 2 for Suppliers 1 and 2, is represented in Figure 4.6, with the highest K/S seen at 6 and 8% cationisation for Supplier 2. All dyeing combinations for both suppliers, show a decrease in K/S at each cationisation level, as the remaining parameters are increased. The only other visible trend is for dyeing combination 3, Supplier 2, which shows a slight decrease in K/S as the cationisation % is increased from 4 to 6 to 8%.

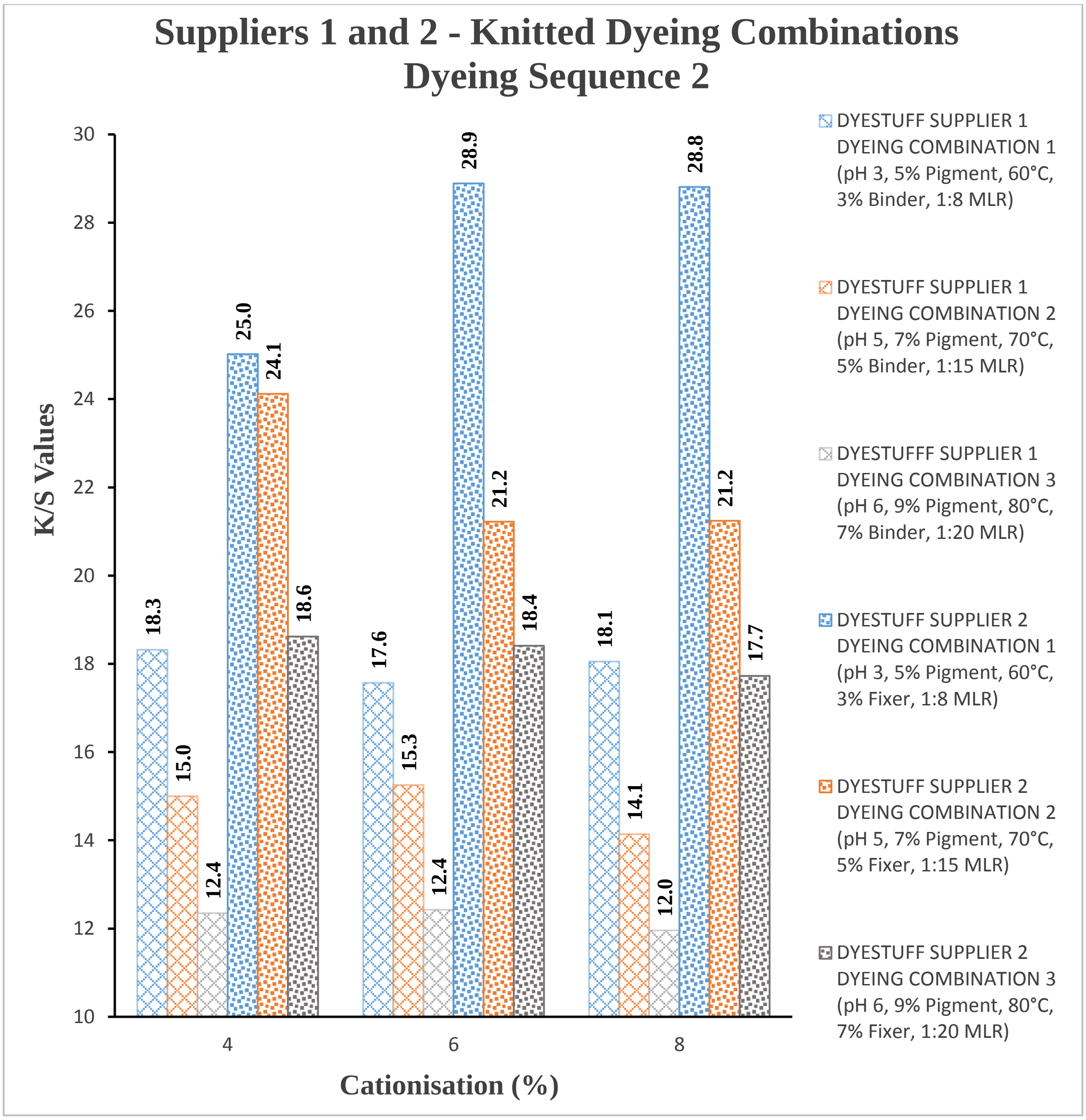


Figure 4.6 Effect of Cationisation Concentration (%) on K/S for the Dyeing Combinations for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

Table 4.7, shows that only Supplier 2 achieves acceptable pass ratings for cationisation at 4, 6 and 8% for dyeing combination 1, and at 4% cationisation for dyeing combination 2, with

Figure 4.7 showing the dyeing combinations that have passed in terms of all fastness with a rating of 3/4.

Table 4.7 Knitted Test Results for Cationisation Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - DYESTUFF SUPPLIER 1																			
Cationisation Trials:							KNITTED											Dyeing Combination Averages	Total Cationisation Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	18.3	5	4	4	4	4	2/3	2/3	2/3	3	18.0	15.0
	6	3	5	60	3	1:8	17.6	5	4	4	4	4	4	2/3	2/3	3		
	8	3	5	60	3	1:8	18.1	5	4/5	4/5	4/5	4/5	3/4	3	3	3/4		
2	4	5	7	70	5	1:15	15.0	5	4/5	4/5	3	3	3	3/4	3	3	14.8	
	6	5	7	70	5	1:15	15.3	5	4/5	4/5	4/5	4/5	3/4	3	3	3		
	8	5	7	70	5	1:15	14.1	5	4/5	4/5	4/5	4/5	2/3	3	3	3		
3	4	6	9	80	7	1:20	12.4	5	4/5	4/5	4/5	4/5	4	3/4	3	3	12.2	
	6	6	9	80	7	1:20	12.4	5	4/5	4/5	4/5	4/5	3	3/4	3	3		
	8	6	9	80	7	1:20	12.0	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3		

SEQUENCE 2 - DYESTUFF SUPPLIER 2																			
Cationisation Trials:							KNITTED											Dyeing Combination Averages	Total Cationisation Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.0	5	4/5	5	5	5	3/4	4	4	4	27.6	22.4
	6	3	5	60	3	1:8	28.9	5	5	4/5	5	5	4/5	3/4	4	4		
	8	3	5	60	3	1:8	28.8	5	5	5	5	5	5	4	4/5	4/5		
2	4	5	7	70	5	1:15	24.1	5	5	5	5	5	4/5	4	4	4	22.2	
	6	5	7	70	5	1:15	21.2	5	4	4	4/5	4/5	2/3	2/3	2	3		
	8	5	7	70	5	1:15	21.2	5	5	5	5	5	2/3	2	3	2/3		
3	4	6	9	80	7	1:20	18.6	5	4/5	4/5	4/5	4/5	3	3	2/3	3	18.3	
	6	6	9	80	7	1:20	18.4	5	5	5	5	5	3	2/3	3	2/3		
	8	6	9	80	7	1:20	17.7	5	4/5	4/5	5	4/5	2/3	2	2	2/3		

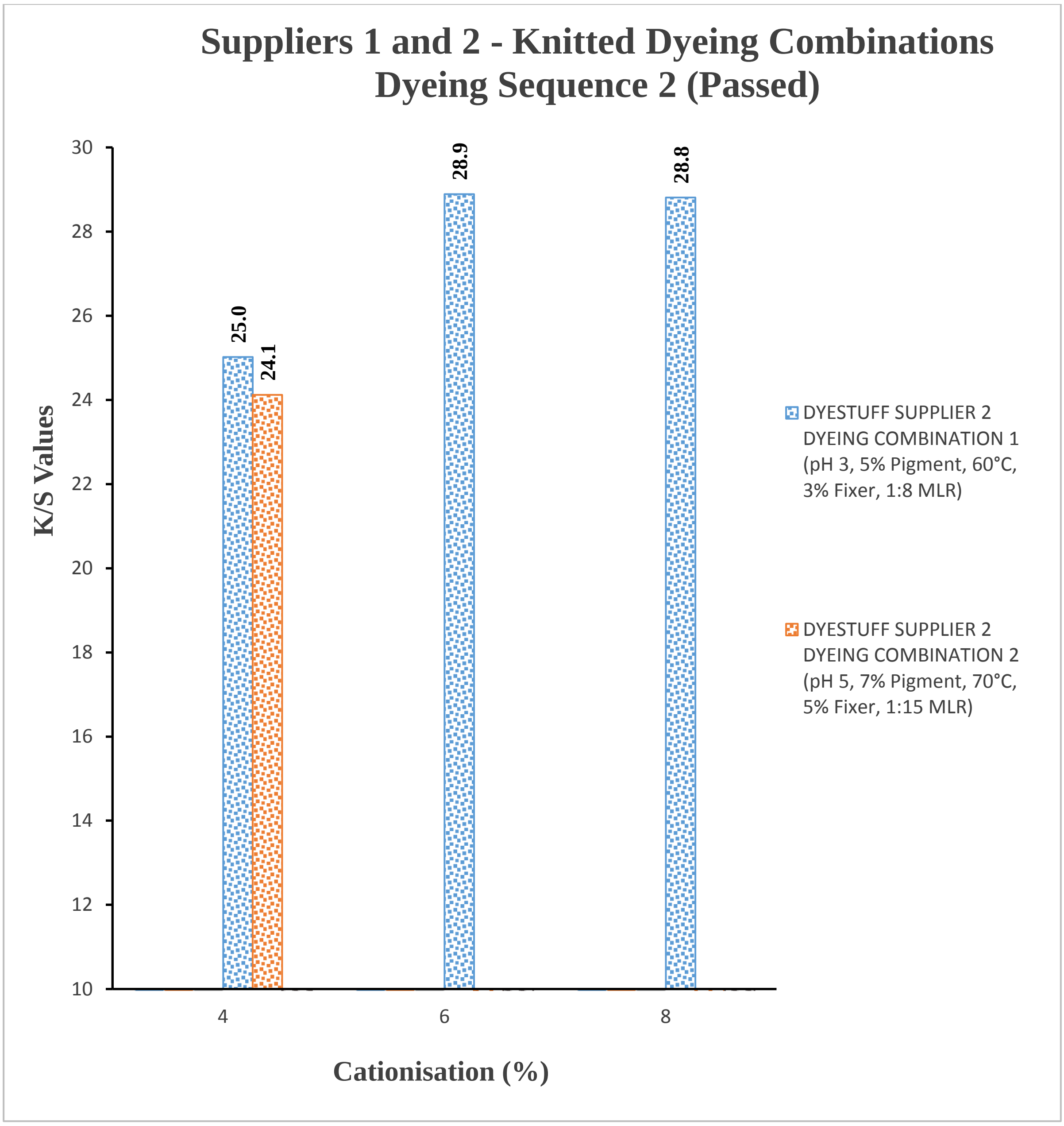


Figure 4.7 Grey Scale Ratings of 3/4 or Higher for Cationisation Concentration Trials for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

4.3.1.3.2. Woven Fabric Results

The K/S for Supplier 2, for dyeing sequence 1 and 2, is represented in Figure 4.8, with the highest K/S seen at 6% cationisation for dyeing sequence 2. All dyeing combinations for sequence 2, for both suppliers, show a decrease in K/S at each cationisation level, as the level of the remaining parameters are increased. A decrease in K/S is also visible for dyeing combination 1, Supplier 1, and dyeing combination 3, Supplier 2, as the cationisation % is increased from 4 to 6%.

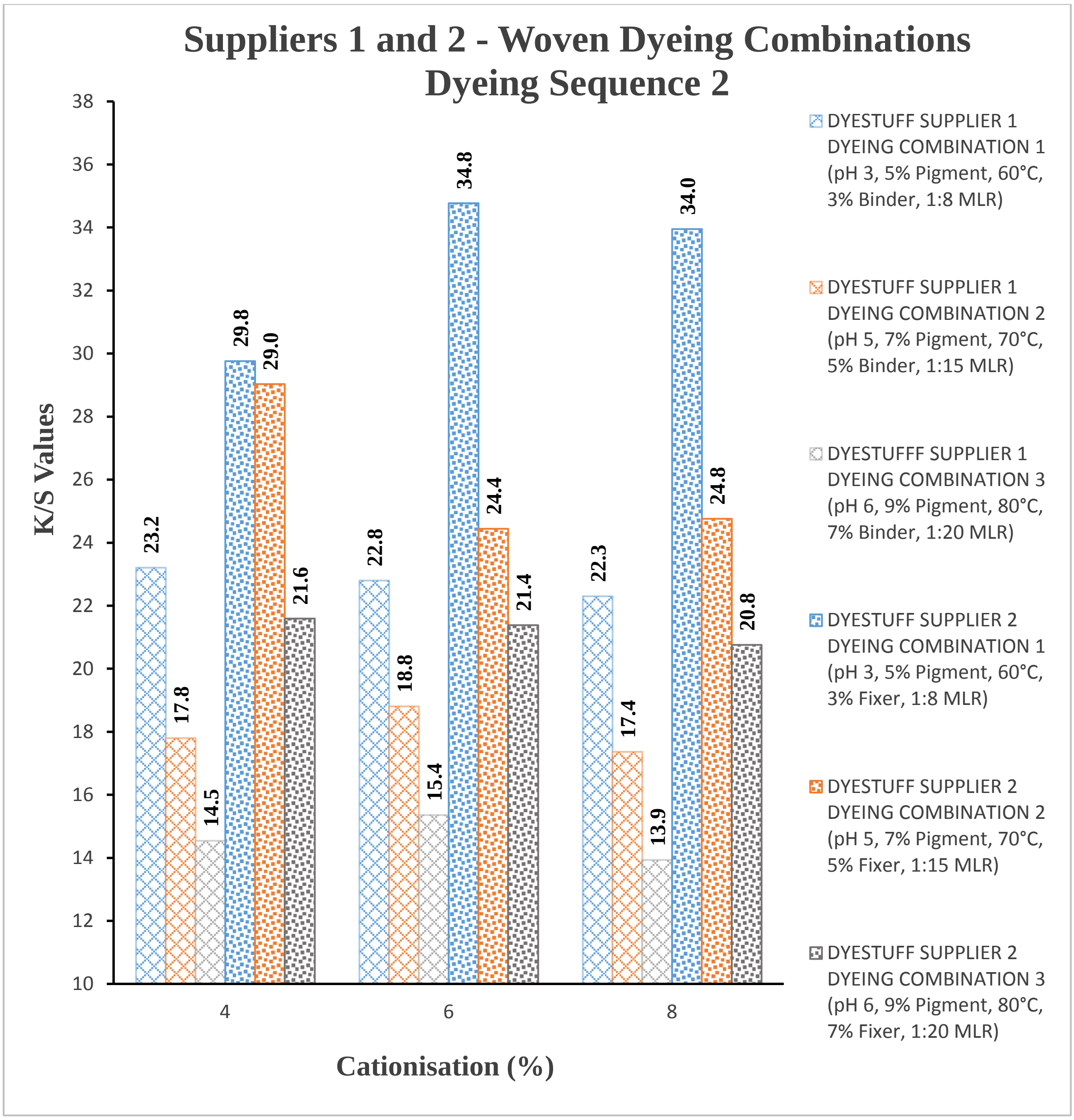


Figure 4.8 Effect of Cationisation Concentration (%) on K/S for the Dyeing Combinations for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

Table 4.8, shows that Supplier 2 achieves acceptable pass ratings for all levels of cationisation for dyeing combination 1, and at 4 and 8% cationisation for dyeing combination 2, as well as at 4% cationisation for dyeing combination 3, with Figure 4.9 showing the dyeing combinations that have passed in terms of all fastness with a rating of 3/4.

Table 4.8 Woven Test Results for Cationisation Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Cationisation Trials:							WOVEN										Dyeing Combination Averages	Total Cationisation Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	23.2	5	4/5	4/5	4/5	4/5	3	3	3	3	22.8	17.9
	6	3	5	60	3	1:8	22.8	5	4/5	4/5	4	4	3/4	3/4	3/4	3		
	8	3	5	60	3	1:8	22.3	5	4/5	4/5	4/5	4/5	3/4	3	3/4	3		
2	4	5	7	70	5	1:15	17.8	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3	18.0	
	6	5	7	70	5	1:15	18.8	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3/4		
	8	5	7	70	5	1:15	17.4	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3		
3	4	6	9	80	7	1:20	14.5	5	4/5	4/5	4/5	4/5	4	3/4	3/4	3/4	14.6	
	6	6	9	80	7	1:20	15.4	4/5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3		
	8	6	9	80	7	1:20	13.9	4/5	4/5	4/5	4/5	4/5	3/4	3	3	3		

SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Cationisation Trials:							WOVEN										Dyeing Combination Averages	Total Cationisation Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	29.8	5	5	5	5	5	4	4	3/4	3/4	32.8	26.3
	6	3	5	60	3	1:8	34.8	5	5	5	5	5	4	4	4	4		
	8	3	5	60	3	1:8	34.0	5	5	5	5	5	4	3/4	3/4	3/4		
2	4	5	7	70	5	1:15	29.0	5	5	5	5	5	4/5	4/5	4	4	26.1	
	6	5	7	70	5	1:15	24.4	5	5	5	5	5	3/4	3	3	4		
	8	5	7	70	5	1:15	24.8	5	5	5	5	5	4	3/4	3/4	3/4		
3	4	6	9	80	7	1:20	21.6	5	5	4/5	5	5	3/4	3/4	3/4	3/4	21.2	
	6	6	9	80	7	1:20	21.4	5	5	5	5	5	3/4	3/4	3	3		
	8	6	9	80	7	1:20	20.8	5	5	5	5	5	3	3	3	2		

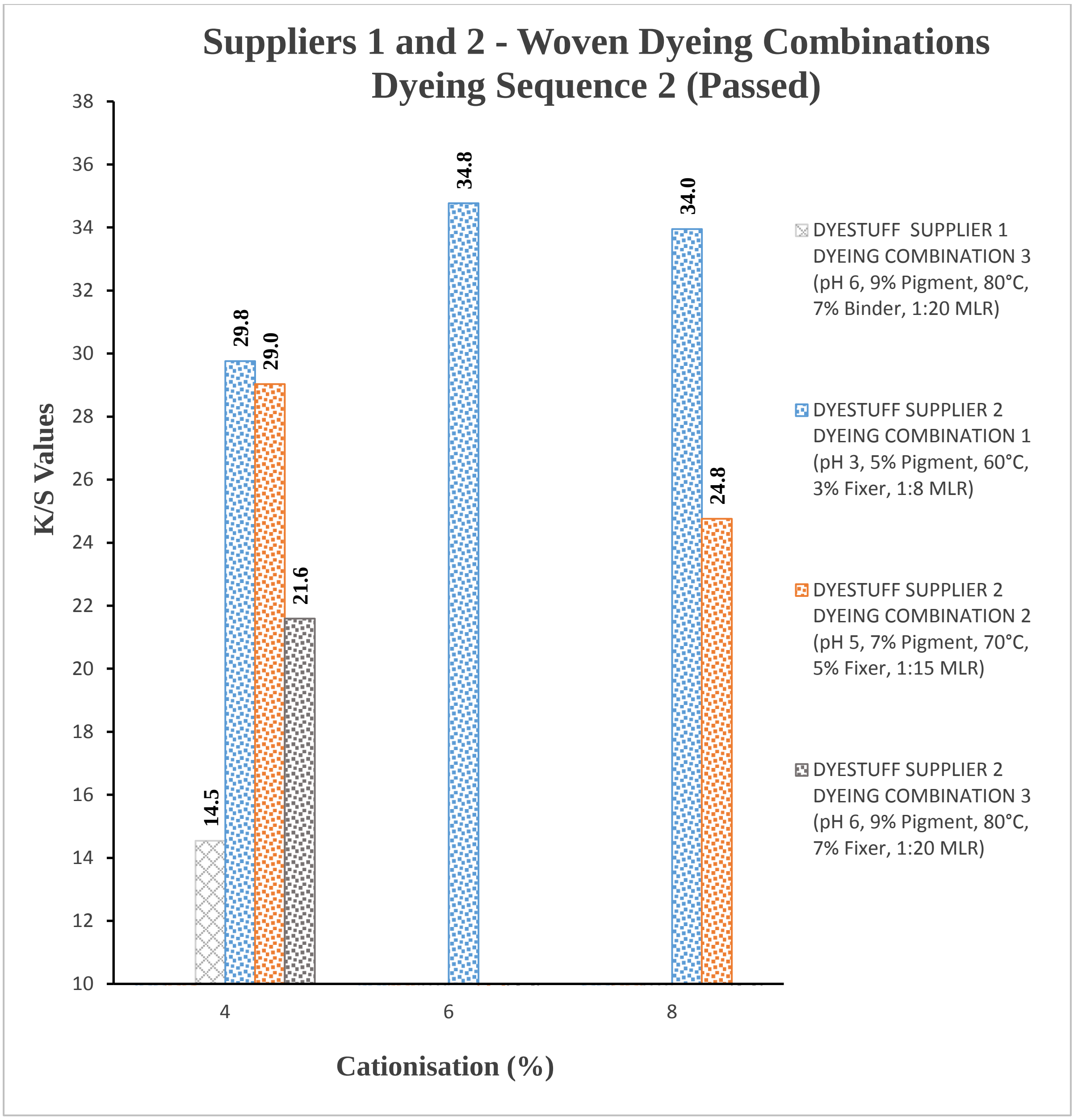


Figure 4.9 Grey Scale Ratings of 3/4 or Higher for Cationisation Concentration Trials for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

4.3.1.4. <u>DISCUSSION</u>

A high K/S was achieved by both dyestuff suppliers, for both fabrics, when lower levels of each parameter were used. Supplier 2 obtained a higher K/S of 29.0 for the knitted fabric compared to that for Supplier 1 with K/S of 18.6, while the woven fabric for Supplier 2 also obtained a higher K/S of 34.8 compared to that for Supplier 1 with K/S of 23.2. Apart from pass ratings of 3/4, for both the knitted and woven fabrics, as indicated in Figures 4.7 and 4.9, respectively, 2 dyeing combinations each for the knitted and woven fabrics, for Supplier 2, achieved pass ratings of 4 or higher in terms of all fastness criteria, with the knitted fabric obtaining the highest K/S of 28.8 at 8% cationisation for dyeing combination 1, while the woven fabric had a higher K/S of 34.8 at 6% cationisation for dyeing combination 1. Tables 4.9 and 4.10, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, for the knitted and woven fabrics, respectively.

Table 4.9 Ideal Dyeing Combinations for Knitted Fabric for Cationisation Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - SUPPLIER 2																	
Cationisation Trials:							KNITTED										
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub		
									Face	Back	Face	Back	Face	Back	Face	Back	
1	8	3	5	60	3	1:8	28.8	5	5	5	5	5	5	4	4/5	4/5	
2	4	5	7	70	5	1:15	24.1	5	5	5	5	5	4/5	4	4	4	

Table 4.10 Ideal Dyeing Combinations for Woven Fabric for Cationisation Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - SUPPLIER 2																
Cationisation Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	6	3	5	60	3	1:8	34.8	5	5	5	5	5	4	4	4	4
2	4	5	7	70	5	1:15	29.0	5	5	5	5	5	4/5	4/5	4	4

4.3.1.5. SUPPLIER 1 (DYEING SEQUENCE 1 AND 2)

Supplier 1 was compared in terms of the two dyeing sequences, with the results discussed hereunder.

4.3.1.5.1. Knitted Fabric Results

The K/S for Supplier 1, for dyeing sequence 1 and 2, is represented in Figure 4.10, with the highest K/S seen at 6% cationisation for dyeing sequence 1. All dyeing combinations for sequence 2, show a decrease in K/S at each cationisation level, as the level of the remaining parameters are increased, with dyeing sequence 1 showing the same trend at 4 and 8% cationisation. A decrease in K/S is also visible for dyeing combinations 1 and 2, for sequence 1, as the cationisation % is increased from 4 to 6 to 8%.

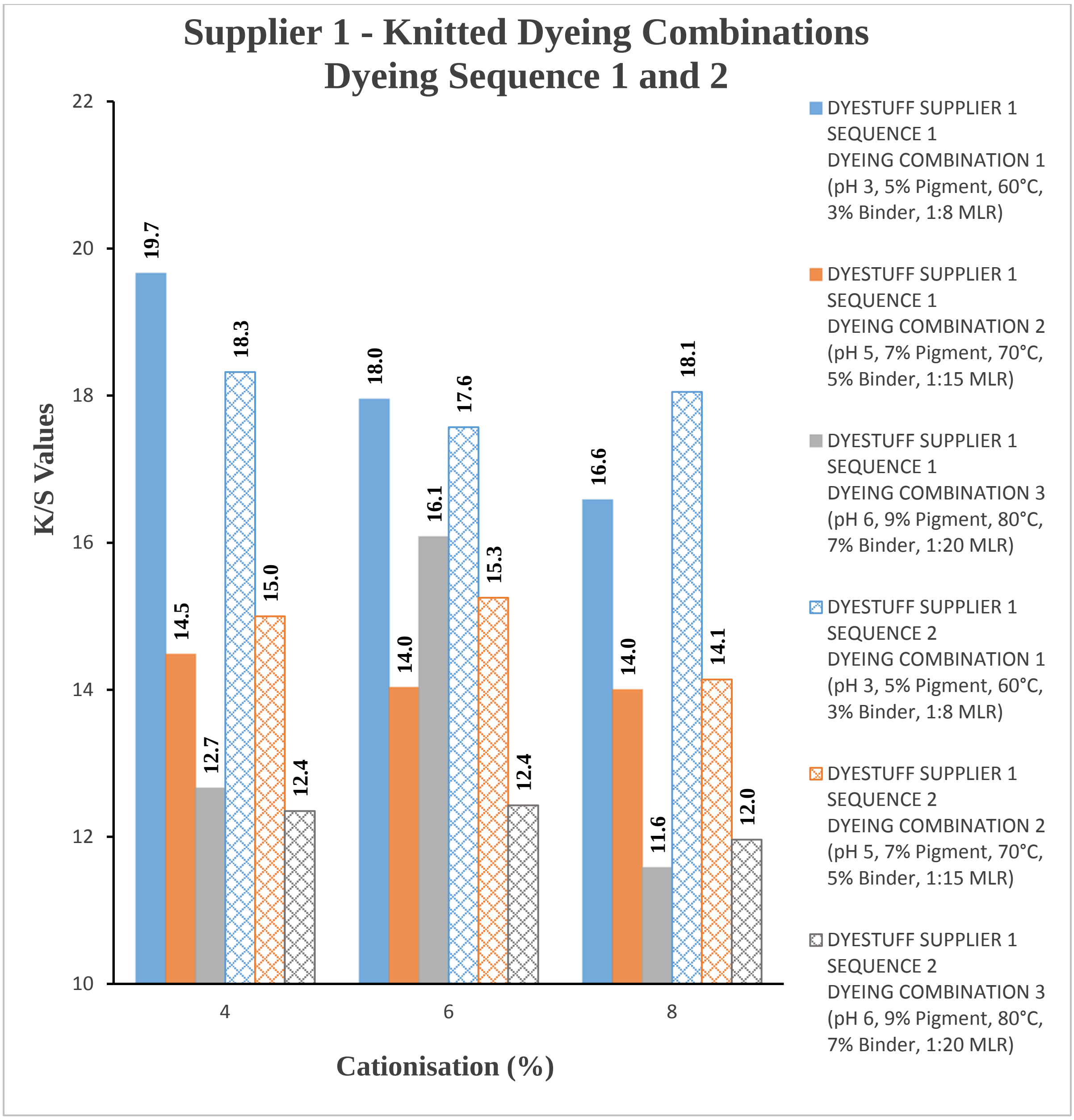


Figure 4.10 Effect of Cationisation Concentration (%) on K/S for the Dyeing Combinations for Knitted Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

Table 4.11, shows that sequence 1 achieves acceptable pass ratings of 3/4 for cationisation at 6 and 8% for dyeing combination 2, and at 4 and 8% cationisation for dyeing combination 3. Sequence 2, however, does not achieve any acceptable pass ratings for all dyeing combinations. In addition, Figure 4.11 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, only dyeing sequence 1 obtains a pass, however with K/S being relatively low.

Table 4.11 Knitted Test Results for Cationisation Concentration Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
Cationisation Trials:							KNITTED										Dyeing Combination Averages	Total Cationisation Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	19.7	4/5	3/4	4/5	3	3/4	2/3	2/3	2	2/3	18.1	15.2
	6	3	5	60	3	1:8	18.0	5	4/5	4/5	4/5	4/5	3	3	3	3		
	8	3	5	60	3	1:8	16.6	5	4/5	4/5	4/5	4/5	2	2/3	2/3	3		
2	4	5	7	70	5	1:15	14.5	4/5	4/5	4/5	4/5	4/5	3	3	3	3	14.2	
	6	5	7	70	5	1:15	14.0	5	4/5	4/5	4/5	4/5	4	3/4	4	4		
	8	5	7	70	5	1:15	14.0	5	4/5	4/5	4/5	4/5	3/4	4	4	4		
3	4	6	9	80	7	1:20	12.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4	13.4	
	6	6	9	80	7	1:20	16.1	5	4/5	4/5	4/5	4/5	2/3	2	2	2		
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4		

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Cationisation Trials:							KNITTED										Dyeing Combination Averages	Total Cationisation Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	18.3	5	4	4	4	4	2/3	2/3	2/3	3	18.0	15.0
	6	3	5	60	3	1:8	17.6	5	4	4	4	4	4	2/3	2/3	3		
	8	3	5	60	3	1:8	18.1	5	4/5	4/5	4/5	4/5	3/4	3	3	3/4		
2	4	5	7	70	5	1:15	15.0	5	4/5	4/5	3	3	3	3/4	3	3	14.8	
	6	5	7	70	5	1:15	15.3	5	4/5	4/5	4/5	4/5	3/4	3	3	3		
	8	5	7	70	5	1:15	14.1	5	4/5	4/5	4/5	4/5	2/3	3	3	3		
3	4	6	9	80	7	1:20	12.4	5	4/5	4/5	4/5	4/5	4	3/4	3	3	12.2	
	6	6	9	80	7	1:20	12.4	5	4/5	4/5	4/5	4/5	3	3/4	3	3		
	8	6	9	80	7	1:20	12.0	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3		

Figure 4.11 Grey Scale Ratings of 3/4 or Higher for Cationisation Concentration Trials for Knitted Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

4.3.1.5.2. Woven Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.12, with the highest K/S seen at 4% cationisation for dyeing sequence 2. All dyeing combinations for dyeing sequence 2, show a decrease in K/S at each cationisation level, as the level of the remaining parameters are increased. However, this is only visible for dyeing sequence 1 at 4 and 8% cationisation. A decrease in K/S is also visible for dyeing combination 1, for sequence 2, as the cationisation % is increased from 4 to 6 to 8%. Furthermore, dyeing combinations 1 and 3 for sequence 1, as well as dyeing combinations 2 and 3 for sequence 2, shows an increase in K/S from 4 to 6% cationisation, followed by a decrease in K/S on further increase in cationisation from 6 to 8%.

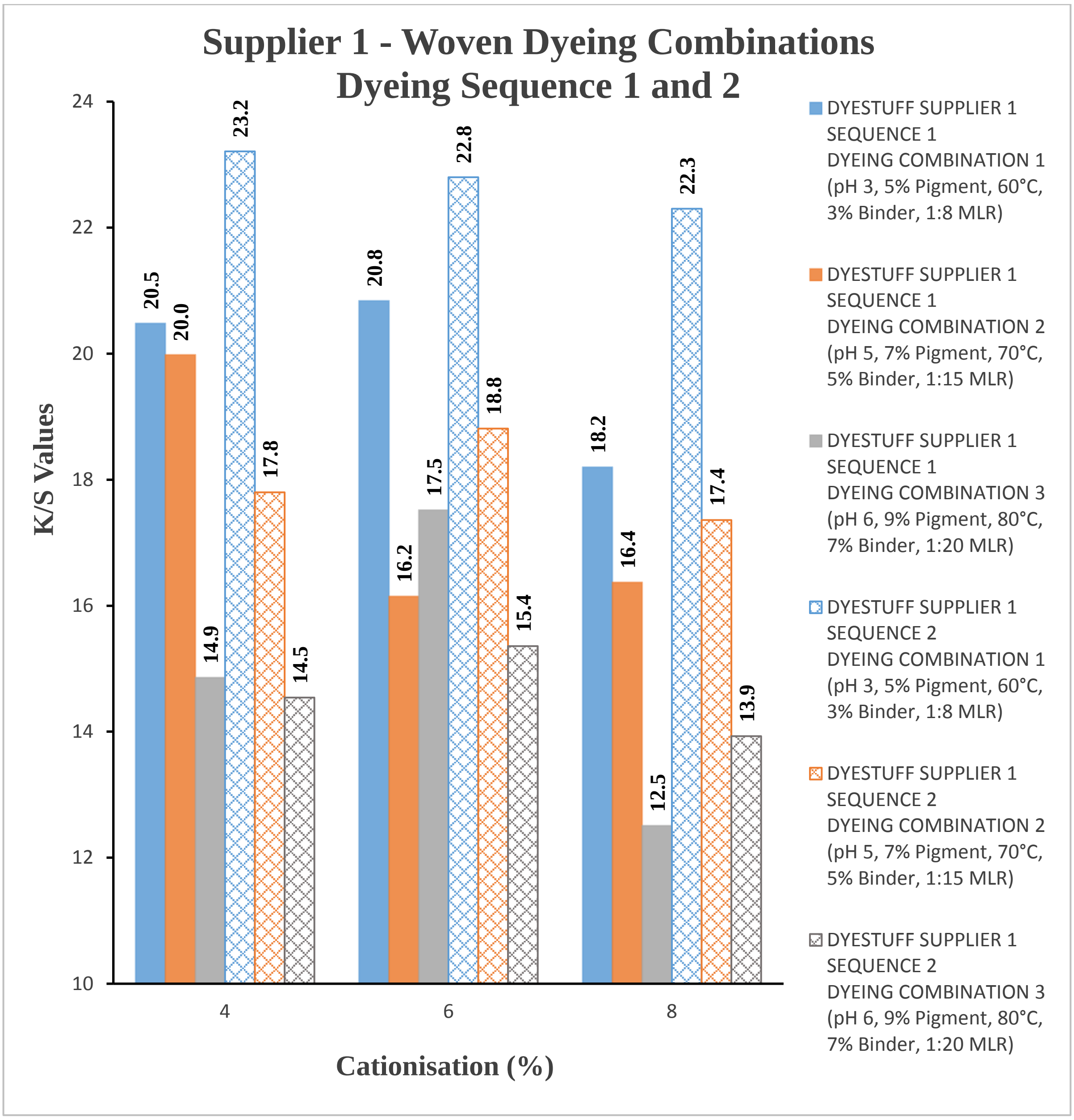


Figure 4.12 Effect of Cationisation Concentration (%) on K/S for the Dyeing Combinations for Woven Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

Table 4.12, shows that dyeing sequence 1 achieves acceptable pass ratings of 3/4 at all levels of cationisation for dyeing combination 1, at 6 and 8% cationisation for dyeing combination 2, and at 4 and 8 % cationisation for dyeing combination 3. Sequence 2, however, only achieves a pass rating at 4% cationisation for dyeing combination 3. In addition, Figure 4.13 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, although dyeing sequence 1 achieves a pass at all levels of cationisation, the corresponding K/S values are lower than those achieved for dyeing sequence 2, therefore making dyeing sequence 2 more preferable as a processing route.

Table 4.12 Woven Test Results for Cationisation Concentration Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
Cationisation Trials:							WOVEN										Dyeing Combination Averages	Total Cationisation Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	20.5	4/5	4/5	4/5	4/5	4/5	4	4/5	3/4	4	19.8	17.1
	6	3	5	60	3	1:8	20.8	4/5	4/5	4/5	4/5	4/5	4	4/5	4	4		
	8	3	5	60	3	1:8	18.2	5	4/5	4	4/5	4	3/4	3/4	3/4	3/4		
2	4	5	7	70	5	1:15	20.0	4/5	4/5	4/5	4/5	4/5	2/3	2/3	3	3/4	17.5	
	6	5	7	70	5	1:15	16.2	5	4/5	4/5	4/5	4/5	4/5	4/5	4	3/4		
	8	5	7	70	5	1:15	16.4	5	4/5	4/5	4/5	4/5	4	4/5	4	4		
3	4	6	9	80	7	1:20	14.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4	15.0	
	6	6	9	80	7	1:20	17.5	4/5	4/5	4/5	4/5	4/5	3/4	4	3	3/4		
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4		
SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Cationisation Trials:							WOVEN										Dyeing Combination Averages	Total Cationisation Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	23.2	5	4/5	4/5	4/5	4/5	3	3	3	3	22.8	17.9
	6	3	5	60	3	1:8	22.8	5	4/5	4/5	4	4	3/4	3/4	3/4	3		
	8	3	5	60	3	1:8	22.3	5	4/5	4/5	4/5	4/5	3/4	3	3/4	3		
2	4	5	7	70	5	1:15	17.8	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3	18.0	
	6	5	7	70	5	1:15	18.8	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3/4		
	8	5	7	70	5	1:15	17.4	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3		
3	4	6	9	80	7	1:20	14.5	5	4/5	4/5	4/5	4/5	4	3/4	3/4	3/4	14.6	
	6	6	9	80	7	1:20	15.4	4/5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3		
	8	6	9	80	7	1:20	13.9	4/5	4/5	4/5	4/5	4/5	3/4	3	3	3		

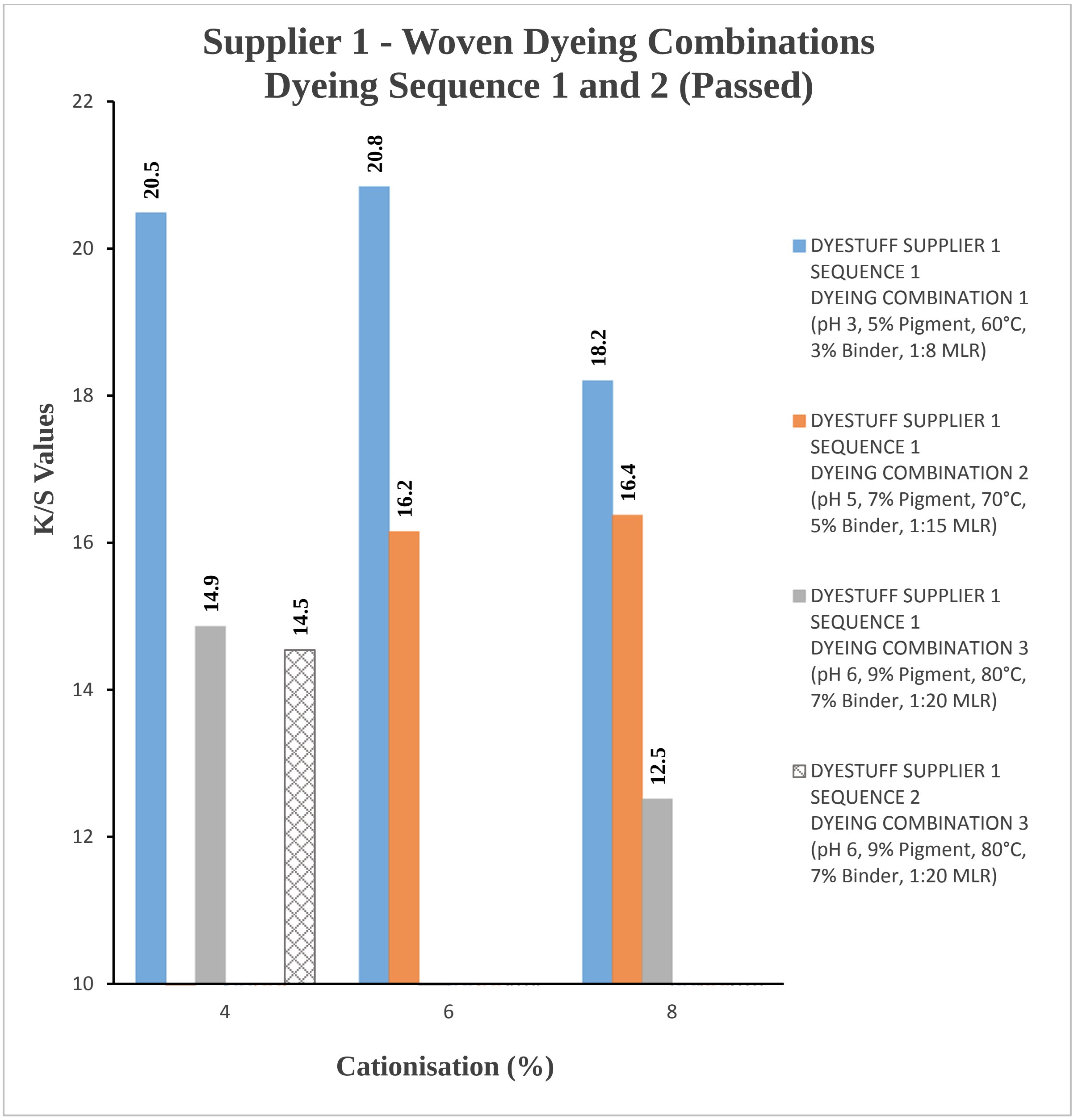


Figure 4.13 Grey Scale Ratings of 3/4 or Higher for Cationisation Concentrations Trials for Woven Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

4.3.1.6. DISCUSSION

Acceptable pass ratings of 3/4, as indicated in Figures 4.11 and 4.13, showed that sequence 1 for the knitted fabric achieved pass ratings for all levels of cationisation, with the woven fabric only achieving a pass rating for sequence 2 at 4% cationisation. In addition, the knitted fabric had 2 dyeing combinations, while the woven fabric had 4 dyeing combinations, which achieved pass ratings of 4 or higher for all fastness, both for sequence 1. Tables 4.13 and 4.14, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for the knitted fabric having a K/S of 12.7 at 4% cationisation for dyeing combination 3, with the woven fabric choice being K/S of 20.8 at 6% cationisation for dyeing combination 1, both for sequence 1, Supplier 1.

Table 4.13 Ideal Dyeing Combinations for Knitted Fabric for Cationisation Concentration Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 1																
Cationisation Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
3	4	6	9	80	7	1:20	12.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4

Table 4.14 Ideal Dyeing Combinations for Woven Fabric for Cationisation Concentration Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 1																
Cationisation Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	6	3	5	60	3	1:8	20.8	4/5	4/5	4/5	4/5	4/5	4	4/5	4	4
2	8	5	7	70	5	1:15	16.4	5	4/5	4/5	4/5	4/5	4	4/5	4	4
3	4	6	9	80	7	1:20	14.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4

4.3.1.7. SUPPLIER 2 (DYEING SEQUENCE 1 AND 2)

Supplier 2 was compared in terms of the two dyeing sequences, with the results discussed hereunder.

4.3.1.7.1. Knitted Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.14, with the highest K/S seen at 8% cationisation for dyeing sequence 1. All dyeing combinations for Supplier 2, for both dyeing sequences, show a decrease in K/S at each cationisation level, as the level of the remaining parameters are increased. An increase in K/S is also visible for dyeing combination 1, for both sequences, as the cationisation % is increased from 4 to 6 to 8%.

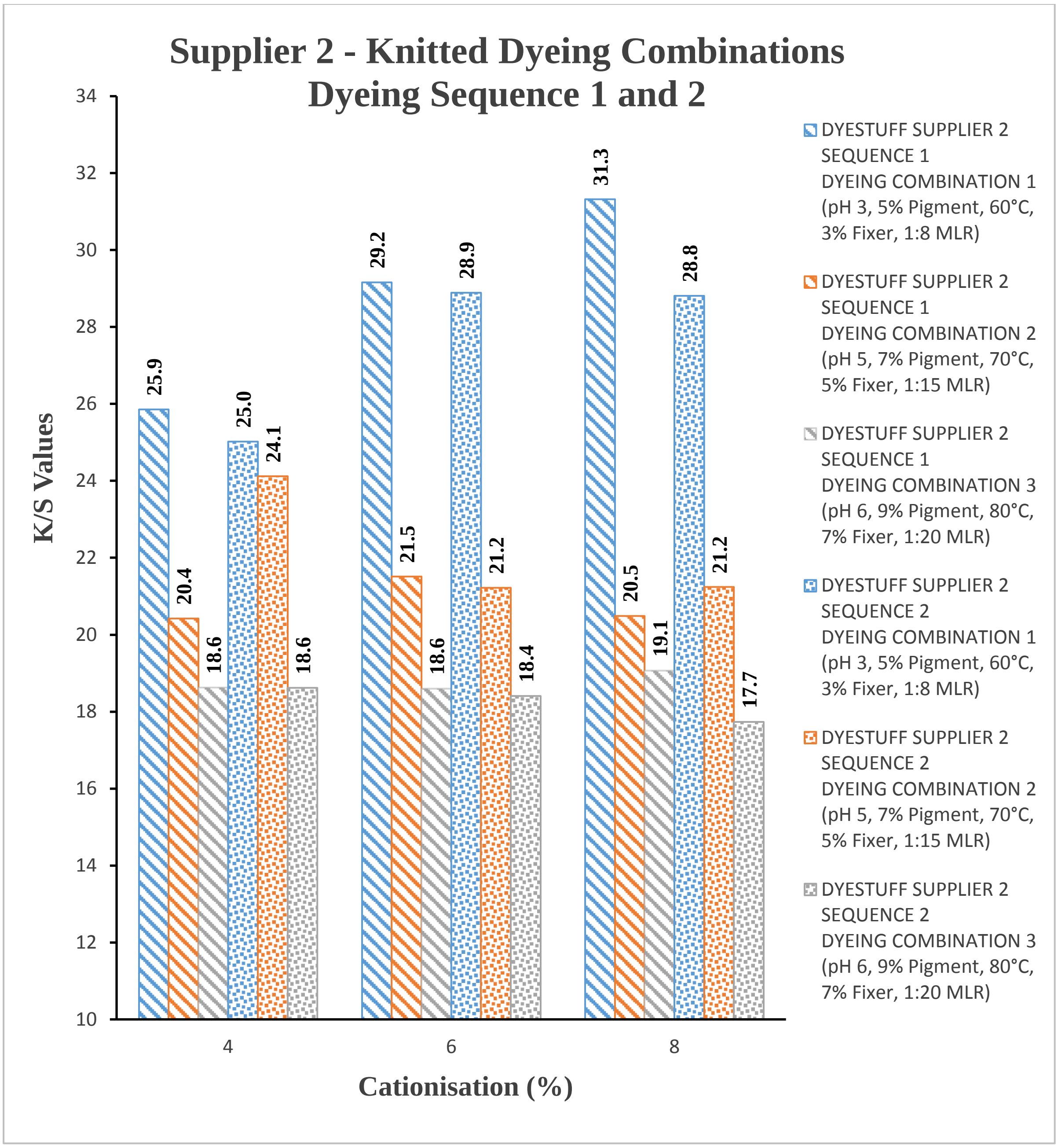


Figure 4.14 Effect of Cationisation Concentration (%) on K/S for the Dyeing Combinations for Knitted Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

Table 4.15, shows that Supplier 2 achieves acceptable pass ratings of 3/4 at all cationisation concentrations for sequence 2. In addition, Figure 4.15 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, sequence 1 did not achieve a pass rating, with sequence 2 attaining K/S values slightly lower than sequence 1.

Table 4.15 Knitted Test Results for Cationisation Concentration Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
Cationisation Trials:							KNITTED										Dyeing Combination Averages	Total Cationisation Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.9	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3	28.8	22.4
	6	3	5	60	3	1:8	29.2	5	4/5	5	5	5	3	3	3	3		
	8	3	5	60	3	1:8	31.3	5	5	5	5	5	4	2/3	3	3		
2	4	5	7	70	5	1:15	20.4	5	5	5	5	4/5	4	2/3	3	3	20.8	
	6	5	7	70	5	1:15	21.5	5	4/5	5	5	4/5	3/4	3	3	3		
	8	5	7	70	5	1:15	20.5	5	5	5	5	5	3	2/3	2/3	3		
3	4	6	9	80	7	1:20	18.6	5	4/5	4/5	5	4/5	2/3	2/3	2/3	3	18.8	
	6	6	9	80	7	1:20	18.6	5	4/5	4/5	4/5	4/5	2/3	2	2	3		
	8	6	9	80	7	1:20	19.1	5	4/5	4/5	5	5	2/3	2/3	2/3	3		
SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Cationisation Trials:							KNITTED										Dyeing Combination Averages	Total Cationisation Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.0	5	4/5	5	5	5	3/4	4	4	4	27.6	22.4
	6	3	5	60	3	1:8	28.9	5	5	4/5	5	5	4/5	3/4	4	4		
	8	3	5	60	3	1:8	28.8	5	5	5	5	5	5	4	4/5	4/5		
2	4	5	7	70	5	1:15	24.1	5	5	5	5	5	4/5	4	4	4	22.2	
	6	5	7	70	5	1:15	21.2	5	4	4	4/5	4/5	2/3	2/3	2	3		
	8	5	7	70	5	1:15	21.2	5	5	5	5	5	2/3	2	3	2/3		
3	4	6	9	80	7	1:20	18.6	5	4/5	4/5	4/5	4/5	3	3	2/3	3	18.3	
	6	6	9	80	7	1:20	18.4	5	5	5	5	5	3	2/3	3	2/3		
	8	6	9	80	7	1:20	17.7	5	4/5	4/5	5	4/5	2/3	2	2	2/3		

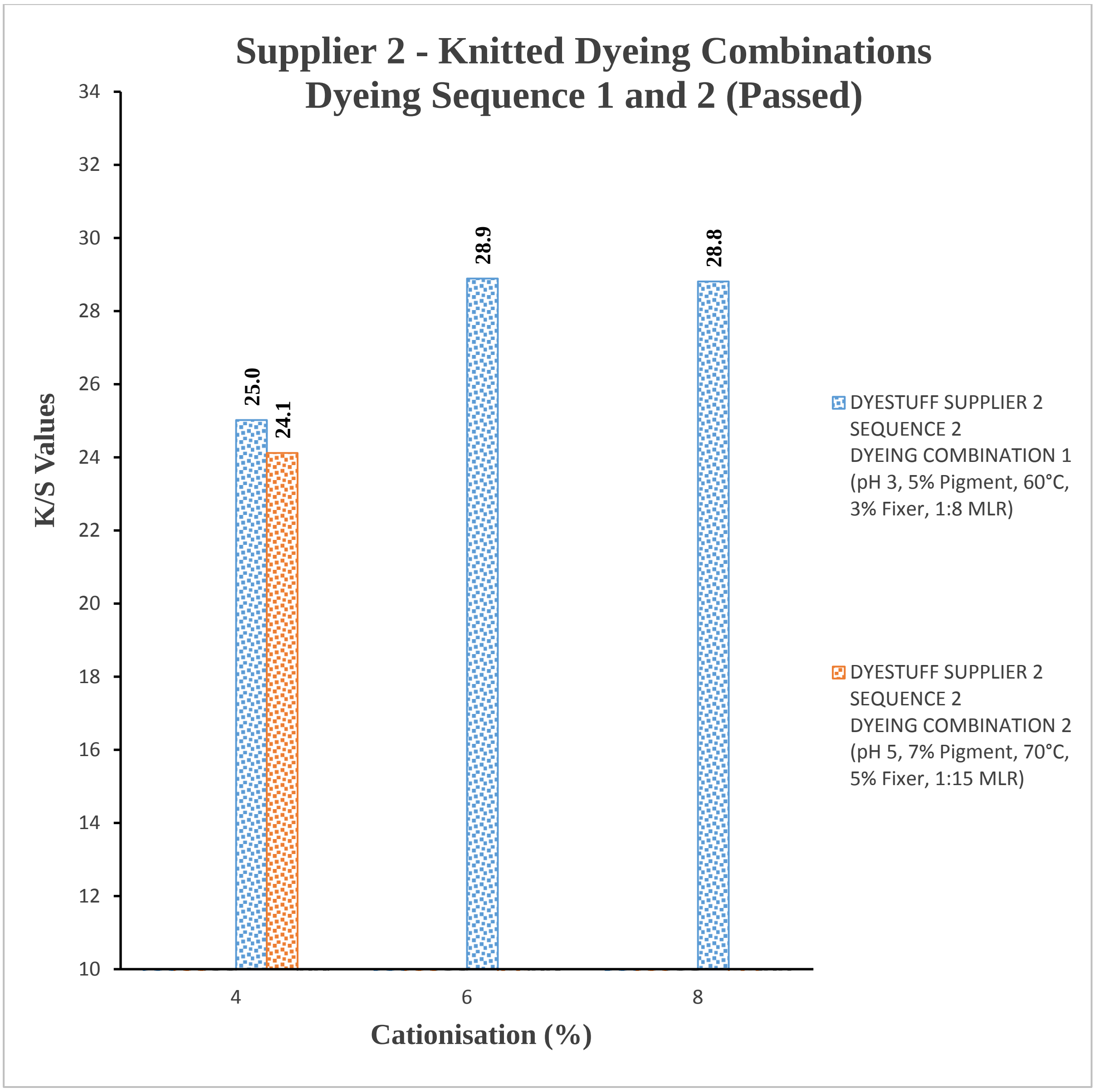


Figure 4.15 Grey Scale Ratings of 3/4 or Higher for Cationisation Concentrations Trials for Knitted Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

4.3.1.7.2. Woven Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.16, with the highest K/S seen at 6% cationisation for dyeing sequence 2. All dyeing combinations for Supplier 2, for both dyeing sequences, show a decrease in K/S at each cationisation level, as the levels of the remaining parameters are increased. An increase in K/S is also visible for dyeing combination 1, for both sequences, as the cationisation % is increased from 4 to 6%, followed by a slight decrease in K/S on further increase in cationisation from 6 to 8%.

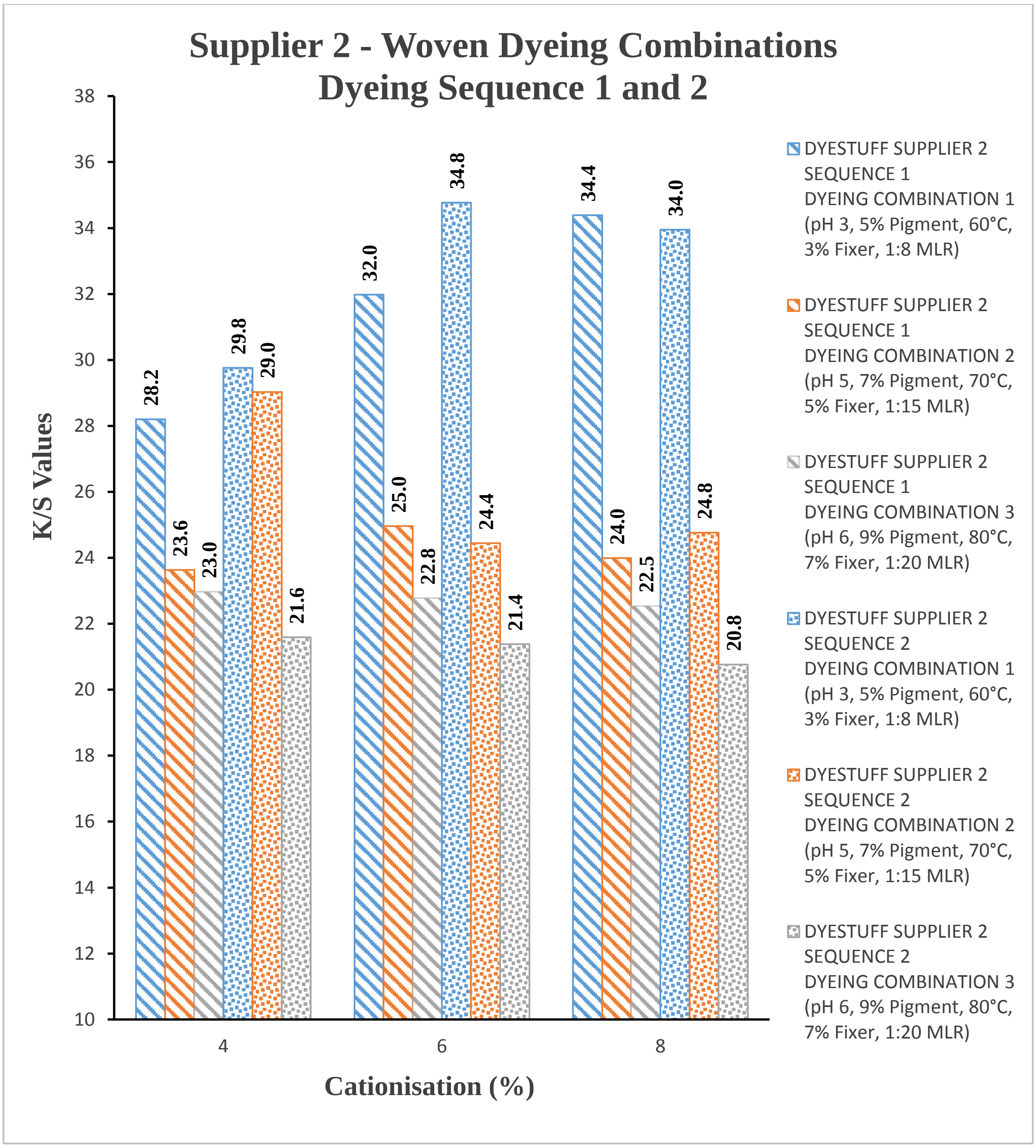


Figure 4.16 Effect of Cationisation Concentration (%) on K/S for the Dyeing Combinations for Woven Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

Table 4.16, shows that Supplier 2 achieves acceptable pass ratings of 3/4 for cationisation at 6% for dyeing combination 1, sequence 1, and at 4, 6 and 8% cationisation for dyeing combination 1, sequence 2, and at 4 and 8 % cationisation for dyeing combination 2, sequence 2, as well as at 6% cationisation for dyeing combination 3, sequence 2. In addition, Figure 4.17 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4, with sequence 2 showing a pass at all levels of cationisation with the highest K/S, while sequence 1 only passes at 6% cationisation.

Table 4.16 Woven Test Results for Cationisation Concentration Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
Cationisation Trials:							WOVEN										Dyeing Combination Averages	Total Cationisation Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	28.2	5	4/5	4/5	5	4/5	3	3	3	2/3	31.5	25.9
	6	3	5	60	3	1:8	32.0	5	5	5	5	5	3/4	3/4	3/4	4		
	8	3	5	60	3	1:8	34.4	5	5	5	5	5	4	3	4	4		
2	4	5	7	70	5	1:15	23.6	5	5	5	5	4/5	4	3	2/3	2/3	24.2	
	6	5	7	70	5	1:15	25.0	5	4/5	4/5	5	4/5	3	3	4	4		
	8	5	7	70	5	1:15	24.0	5	5	5	5	4/5	3/4	3	4	3		
3	4	6	9	80	7	1:20	23.0	5	4/5	4/5	5	4/5	4	4/5	3	2/3	22.8	
	6	6	9	80	7	1:20	22.8	5	5	4/5	5	4/5	4	3	3	3		
	8	6	9	80	7	1:20	22.5	5	5	5	5	4/5	3	4	3/4	3		
SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Cationisation Trials:							WOVEN										Dyeing Combination Averages	Total Cationisation Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	29.8	5	5	5	5	5	4	4	3/4	3/4	32.8	26.3
	6	3	5	60	3	1:8	34.8	5	5	5	5	5	4	4	4	4		
	8	3	5	60	3	1:8	34.0	5	5	5	5	5	4	3/4	3/4	3/4		
2	4	5	7	70	5	1:15	29.0	5	5	5	5	5	4/5	4/5	4	4	26.1	
	6	5	7	70	5	1:15	24.4	5	5	5	5	5	3/4	3	3	4		
	8	5	7	70	5	1:15	24.8	5	5	5	5	5	4	3/4	3/4	3/4		
3	4	6	9	80	7	1:20	21.6	5	5	4/5	5	5	3/4	3/4	3/4	3/4	21.2	
	6	6	9	80	7	1:20	21.4	5	5	5	5	5	3/4	3/4	3	3		
	8	6	9	80	7	1:20	20.8	5	5	5	5	5	3	3	3	2		

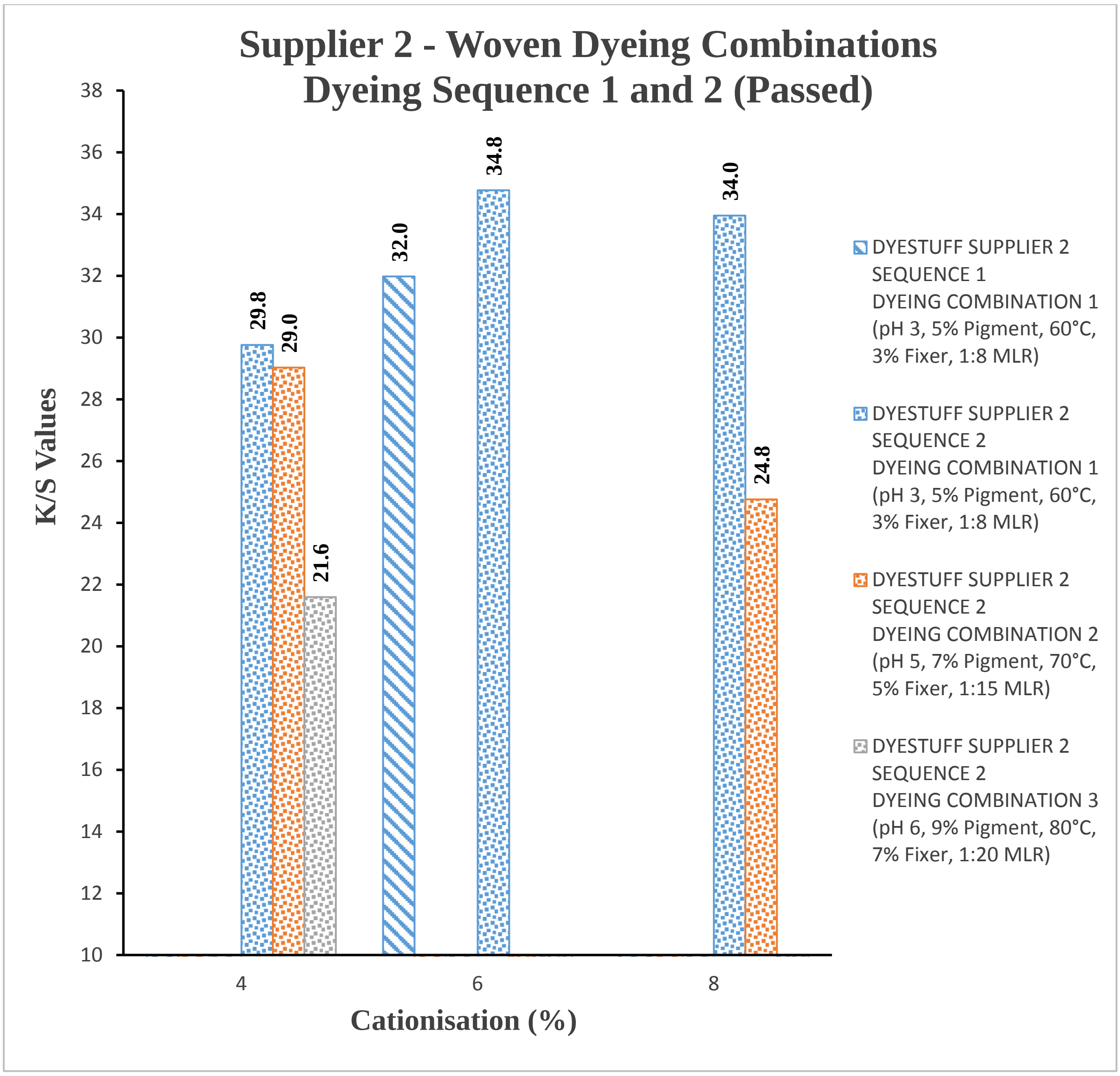


Figure 4.17 Grey Scale Ratings of 3/4 or Higher for Cationisation Concentrations Trials for Woven Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

4.3.1.8. DISCUSSION

Acceptable pass ratings of 3/4, as indicated in Figures 4.15 and 4.17, showed that sequence 1, achieved a pass rating at 6% cationisation, for the woven fabric only, while sequence 2, achieved pass ratings, for both knitted and woven fabrics, at all levels of cationisation. However, no dyeing combinations, for the knitted fabric, for either sequence 1 or 2, achieved pass ratings of 4 or higher for any fastness, while 2 dyeing combinations, for the woven fabric, for sequence 2, achieved pass ratings of 4 or higher for all fastness. Table 4.17, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher for the woven fabric, with the ideal choice being K/S of 34.8 at 6% cationisation for dyeing combination 1, for sequence 2.

Table 4.17 Ideal Dyeing Combinations for Woven Fabric for Cationisation Concentration Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 2 - SUPPLIER 2																		
Cationisation Trials:							WOVEN											
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	6	3	5	60	3	1:8	34.8	5	5	5	5	5	4	4	4	4		
2	4	5	7	70	5	1:15	29.0	5	5	5	5	5	4/5	4/5	4	4		

4.3.1.9. CONCLUSION

To conclude the results for all cationisation concentration trials for each supplier and sequence, the average K/S was taken into account. The effect of cationisation concentration on K/S, for both knitted and woven fabrics, for both suppliers and sequences showed a decrease in K/S as the cationisation concentration increased from 4 to 6 to 8% for all dyeing combinations, while the other 5 parameters (pH, pigment, temperature, binder/fixer and MLR) increased in their respective levels.

The knitted fabric for both suppliers achieved a slightly higher average K/S for dyeing sequence 1 compared to that for dyeing sequence 2, in contrast to the woven fabric which achieved a higher K/S for dyeing sequence 2 compared to that for dyeing sequence 1, for both suppliers. Furthermore, both dyeing sequences for Supplier 2, achieved higher average K/S values compared to that for Supplier 1, for both fabrics. In addition, the K/S values for all woven fabric were higher compared to that for the knitted fabric, with the reasons for this difference being explained in section 4.3.7.

Taking the K/S values into account, it can be concluded that sequence 2 for Supplier 2, achieved the ideal cationisation concentration for the knitted fabric at 8% (K/S of 28.8) while that for the woven fabric was at 6% (K/S of 34.8). In addition, these K/S values also achieved Grey Scale ratings of 4 or higher for all fastness criteria. These ideal cationisation concentrations are also supported by previous works carried out by Fang *et al* (2005), Patra *et al* (2006), Ristić and Ristić (2012), Kumar *et al* (2013), Wu and Zhang (2013), Choudhury (2014) and Saha and Dina (2015), which reported that cationisation concentrations between 6 and 8% obtained good results for K/S.

4.3.2. Effect of pH Level

The two dyestuff suppliers were compared with one another to determine the effect of pH on the outcome of K/S and fastness, when the pH levels were increased from 3 to 5 to 6, while the other 5 parameters (cationisation, pigment, temperature, binder/fixer and MLR) were kept constant, with 3 trials per dyeing combination. The results from the pH trials, for both suppliers and sequences will be concluded in section 4.3.7. The dyeing combinations used in the pH level trials are presented in Table 4.18, with the results presented graphically.

Table 4.18 Dyeing Combinations for pH Level Trials.

	pH Level Trials						
	Cationisation (%)	**pH**	**Pigment (%)**	**Temp (°C)**	**Binder/ Fixer (%)**	**MLR**	**Trial No.**
Combination 1	4	3	5	60	3	1:8	1
	4	5	5	60	3	1:8	4
	4	6	5	60	3	1:8	7
Combination 2	6	3	7	70	5	1:15	2
	6	5	7	70	5	1:15	5
	6	6	7	70	5	1:15	8
Combination 3	8	3	9	80	7	1:20	3
	8	5	9	80	7	1:20	6
	8	6	9	80	7	1:20	9

4.3.2.1. SUPPLIERS 1 AND 2 (DYEING SEQUENCE 1)

4.3.2.1.1. Knitted Fabric Results

The K/S values for both dyestuff suppliers, for dyeing sequence 1, is represented in Figure 4.18, which shows that the K/S for the knitted fabric for Supplier 2 is higher than that for Supplier 1; with the greatest K/S observed at a pH of 3. Supplier 1 shows a decrease in K/S at a pH of 5 and 6, for all dyeing combinations, as the levels of the remaining parameters are increased, while Supplier 2 exhibits the same trend at a pH of 3 and 5. Furthermore, Supplier 1 also shows a decrease in K/S for dyeing combinations 1, as the pH level increases from 3 to 5 to 6.

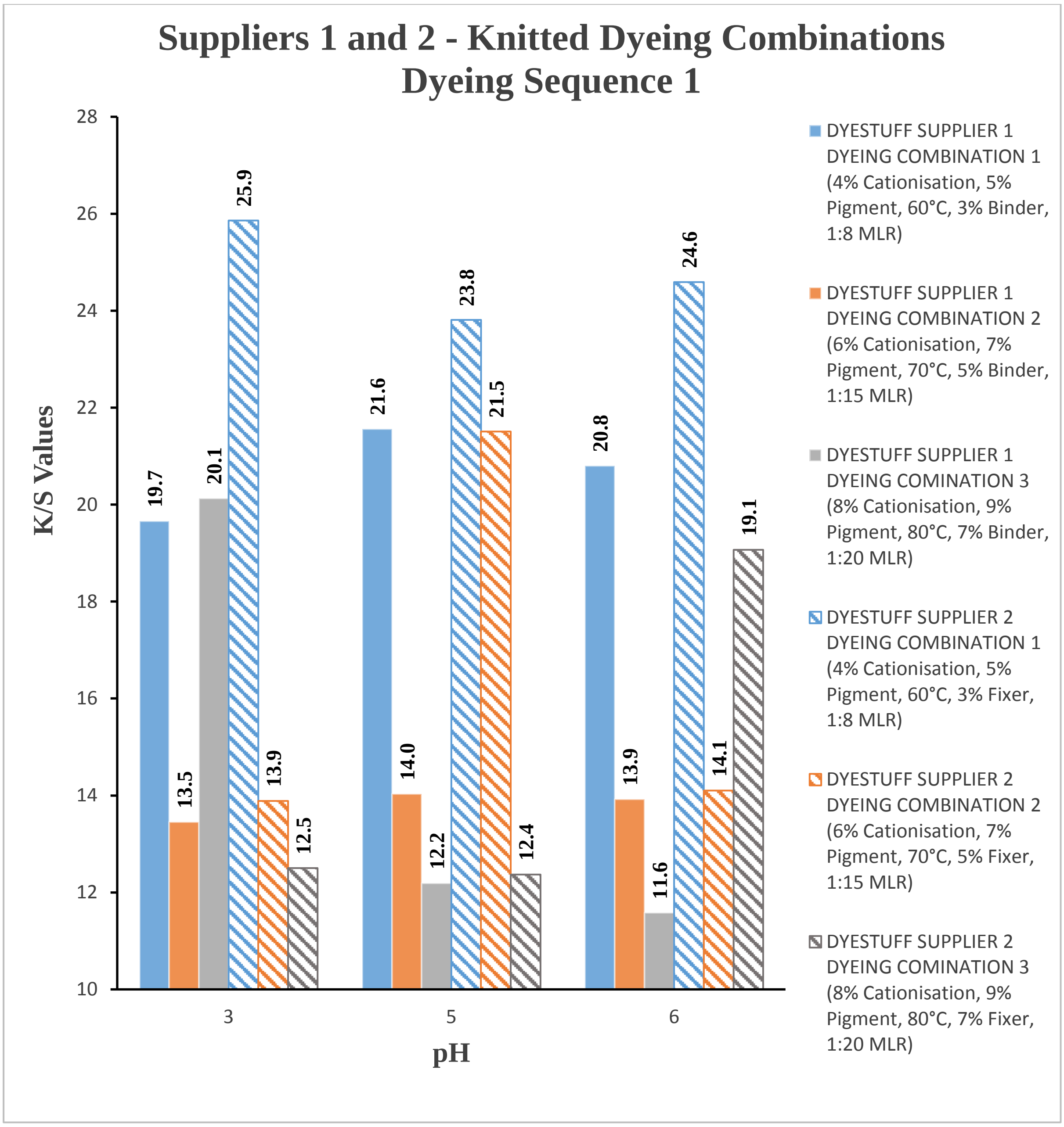


Figure 4.18 Effect of pH Level on K/S for the Dyeing Combinations for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

Table 4.19, shows that Supplier 1 achieves the acceptable pass ratings at a pH of 6 for dyeing combination 1, at a pH of 3 and 5 for dyeing combination 2, and at all pH levels for dyeing combination 3. Supplier 2, which has a higher K/S than that for Supplier 1, does not achieve any acceptable pass ratings for all pH dyeing combinations. In addition, Figure 4.19 shows the dyeing combinations that have passed in terms of all fastness with a rating of 3/4. Accordingly, only dyestuff Supplier 1 passed in terms of all the fastness criteria, with the corresponding K/S values being relatively lower than that for Supplier 2.

Table 4.19 Knitted Test Results for pH Level Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
pH Trials:							KNITTED										Dyeing Combination Averages	Total pH Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
	4	3	5	60	3	1:8	19.7	4/5	3/4	4/5	3	3/4	2/3	2/3	2	2/3		
1	4	5	5	60	3	1:8	21.6	4/5	4/5	4/5	4/5	4/5	3	3	3	3	20.6	
	4	6	5	60	3	1:8	20.8	4/5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	4		
	6	3	7	70	5	1:15	13.5	4/5	4/5	4	4/5	4/5	3/4	3/4	3/4	3/4		
2	6	5	7	70	5	1:15	14.0	5	4/5	4/5	4/5	4/5	4	3/4	4	4	16.1	16.4
	6	6	7	70	5	1:15	13.9	4/5	4/5	4	4	4/5	3/4	3	3/4	3/4		
	8	3	9	80	7	1:20	20.1	4/5	5	4/5	4/5	4/5	4	3/4	3/4	3/4		
3	8	5	9	80	7	1:20	12.2	4/5	5	4/5	5	5	4	4	4	4/5	15.4	
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4		

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
pH Trials:							KNITTED										Dyeing Combination Averages	Total pH Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
	4	3	5	60	3	1:8	25.9	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3		
1	4	5	5	60	3	1:8	23.8	5	5	5	4/5	4/5	2/3	3	2	2/3	24.8	
	4	6	5	60	3	1:8	24.6	5	4/5	4/5	4/5	4/5	2/3	2/3	2	2/3		
	6	3	7	70	5	1:15	13.9	5	4/5	4/5	4/5	4/5	3	3	3	3		
2	6	5	7	70	5	1:15	21.5	5	4/5	5	5	4/5	3/4	3	3	3	16.5	17.7
	6	6	7	70	5	1:15	14.1	4/5	4/5	4/5	4/5	4/5	2/3	2/3	2/3	2/3		
	8	3	9	80	7	1:20	12.5	5	5	5	5	5	3	3	3/4	4		
3	8	5	9	80	7	1:20	12.4	5	4/5	4/5	4/5	4/5	2	1/2	3	2/3	14.6	
	8	6	9	80	7	1:20	19.1	5	4/5	4/5	5	5	2/3	2/3	2/3	3		

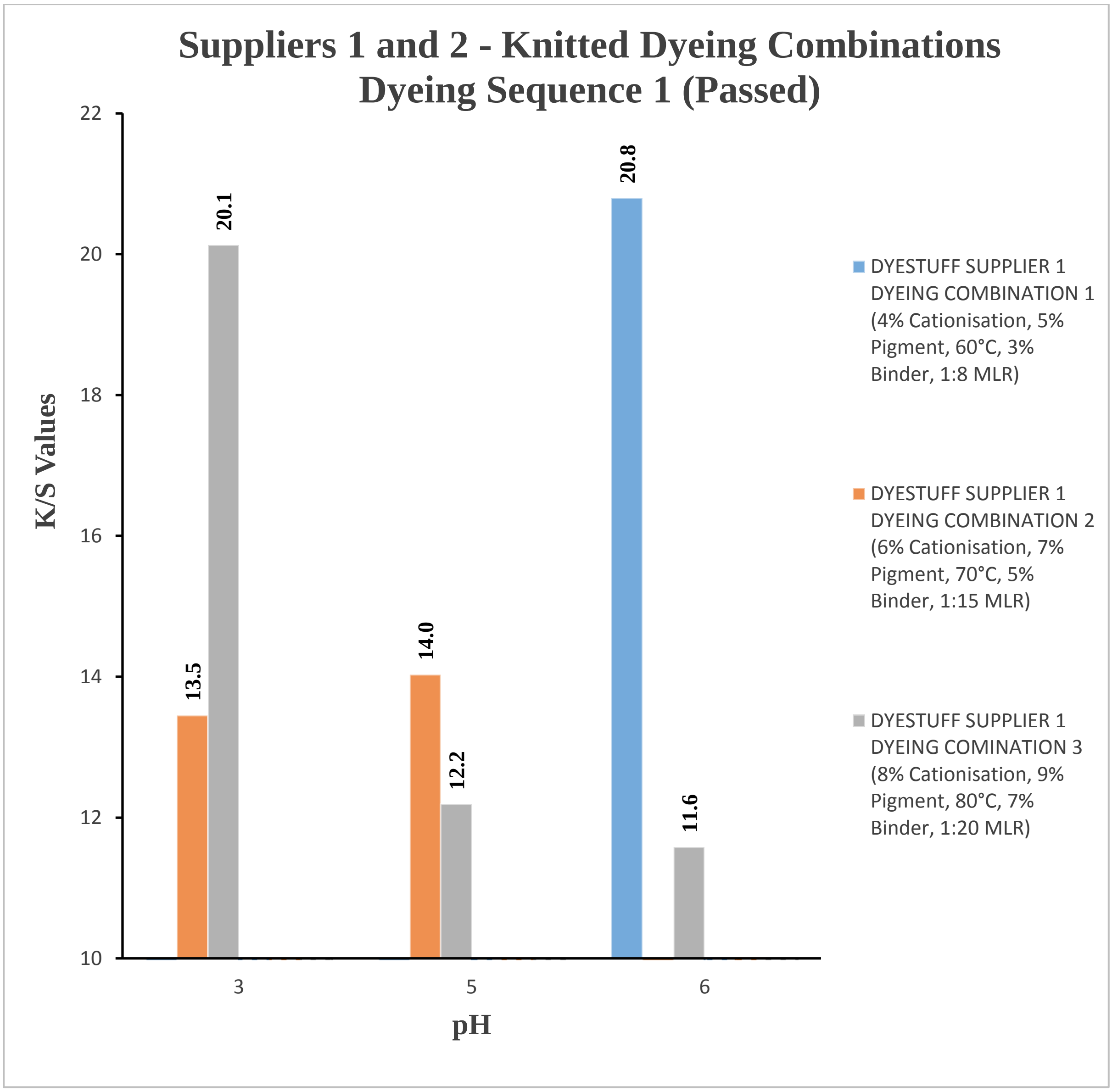


Figure 4.19 Grey Scale Ratings of 3/4 or Higher for pH Level Trials for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

4.3.2.1.2. Woven Fabric Results

The K/S for both dyestuff suppliers is represented in Figure 4.20, which shows that the K/S for the woven fabric, for Supplier 2 is greater than that for Supplier 1; and is greatest at a pH of 3 and 6. Suppliers 1 and 2, show a decrease in K/S at each level of pH, as the levels of the remaining parameters are increased. Supplier 1, for dyeing combinations 2 and 3, show a slight decrease in K/S as pH levels increase from 3 to 5 to 6.

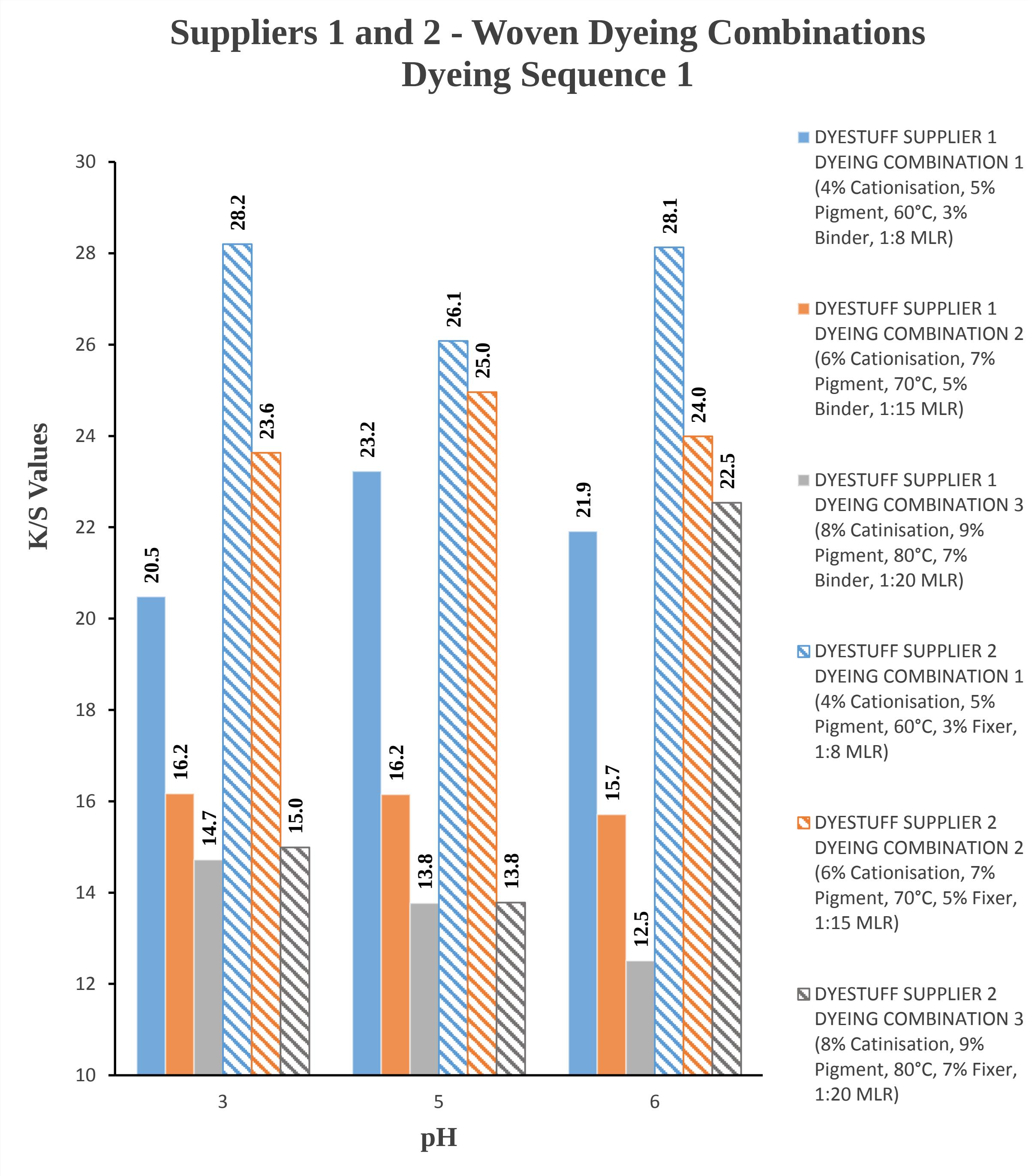


Figure 4.20 Effect of pH Level on K/S for the Dyeing Combinations for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

Table 4.20, shows that Supplier 1 achieves acceptable pass ratings at a pH of 3 and 5 for dyeing combinations 1 and 2, and at all pH levels for dyeing combination 3, whereas Supplier 2, only achieves an acceptable pass rating at a pH of 3 for dyeing combination 3. In addition, Figure 4.21 shows the dyeing combinations that have passed on all fastness with a rating of 3/4. Accordingly, only dyestuff Supplier 1 passed in terms of all the fastness criteria, with the corresponding K/S values being lower than that of Supplier 2.

Table 4.20 Woven Test Results for pH Level Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
pH Trials:							WOVEN										Dyeing Combination Averages	Total pH Average
									Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	20.5	4/5	4/5	4/5	4/5	4/5	4	4/5	3/4	4	21.9	16.8
	4	5	5	60	3	1:8	23.2	4/5	4/5	4/5	4/5	4/5	3/4	4	3/4	3/4		
	4	6	5	60	3	1:8	21.9	4/5	4/5	4/5	4/5	4	3/4	3/4	3	3		
2	6	3	7	70	5	1:15	16.2	4/5	4	4/5	4/5	4	3/4	4	3/4	4	16.0	
	6	5	7	70	5	1:15	16.2	5	4/5	4/5	4/5	4/5	4/5	4/5	4	3/4		
	6	6	7	70	5	1:15	15.7	4/5	4/5	4/5	4	4/5	3/4	3/4	3	3/4		
3	8	3	9	80	7	1:20	14.7	4/5	4/5	4/5	4/5	5	4	4	3/4	4	13.7	
	8	5	9	80	7	1:20	13.8	4/5	5	4/5	5	4/5	4	4	3/4	3/4		
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4		

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
pH Trials:							WOVEN										Dyeing Combination Averages	Total pH Average
									Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	28.2	5	4/5	4/5	5	4/5	3	3	3	2/3	27.5	22.5
	4	5	5	60	3	1:8	26.1	5	4/5	4/5	4/5	4/5	3	3	3	2		
	4	6	5	60	3	1:8	28.1	5	5	5	5	5	3	3	3	3		
2	6	3	7	70	5	1:15	26.9	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3/4	24.8	
	6	5	7	70	5	1:15	25.0	5	4/5	4/5	5	4/5	3	3	4	4		
	6	6	7	70	5	1:15	22.5	5	4/5	4/5	4/5	4/5	3	3	3	3		
3	8	3	9	80	7	1:20	15.0	5	4/5	4/5	5	5	4/5	4/5	4	3/4	17.1	
	8	5	9	80	7	1:20	13.8	5	4/5	4/5	5	5	3/4	3	3	2/3		
	8	6	9	80	7	1:20	22.5	5	5	5	5	4/5	3	4	3/4	3		

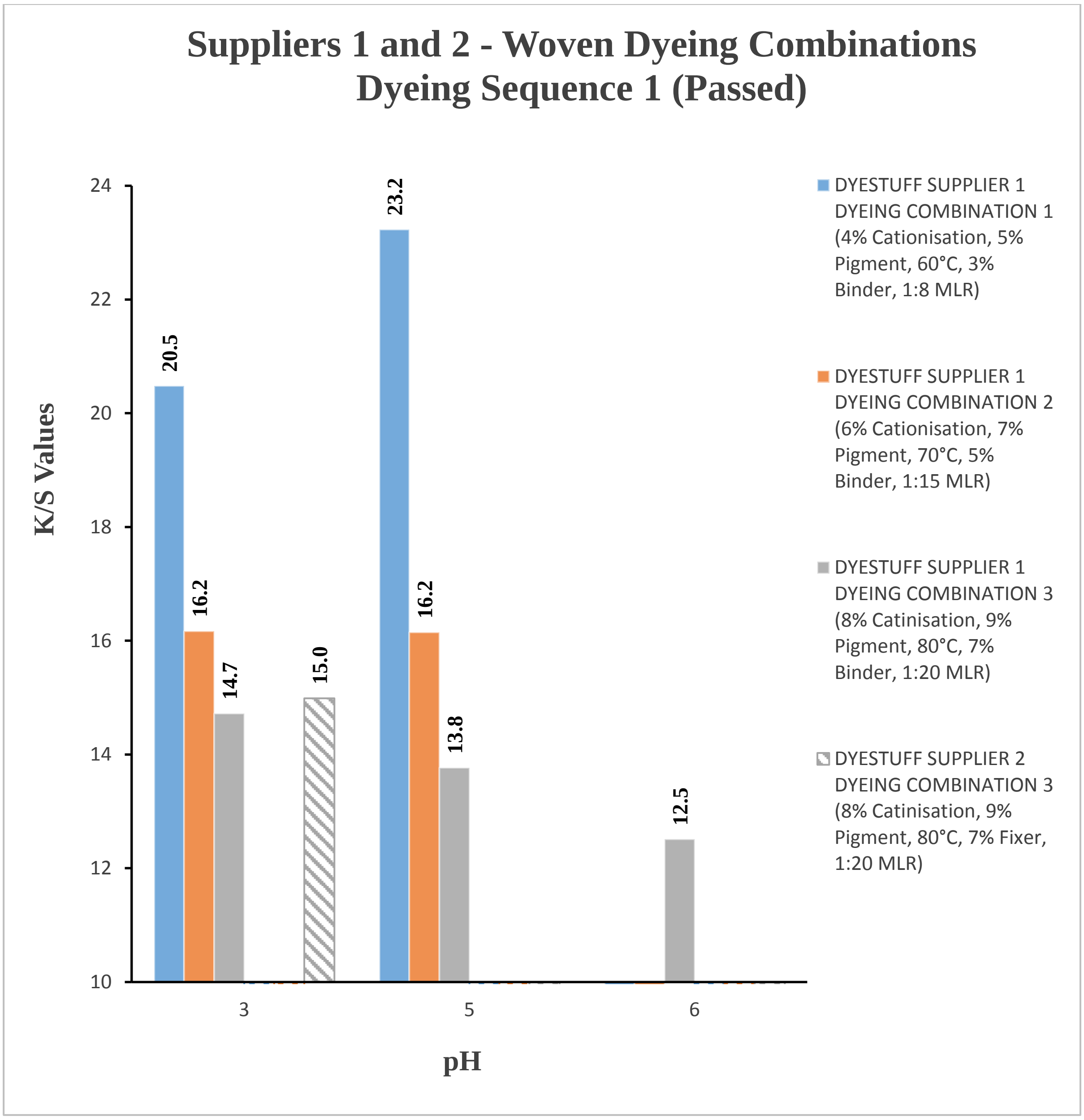


Figure 4.21 Grey Scale Ratings of 3/4 or Higher for pH Level Trials for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

4.3.2.2. <u>DISCUSSION</u>

Supplier 2 obtained higher K/S than that for Supplier 1, for the knitted and woven fabrics. Acceptable pass ratings of 3/4, as indicated in Figures 4.19 and 4.21, show that Supplier 1 again obtains a pass at all levels of pH. In addition, one dyeing combination each, for the knitted and woven fabric, for Supplier 1, achieved a pass rating of 4 or higher for all fastness criteria, with the knitted fabric having the highest K/S of 12.1 at a pH of 5 for dyeing combination 3, while the woven fabric had a K/S of 12.5 at a pH of 6 for dyeing combination 3, with both values being very similar. Tables 4.21 and 4.22, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, for the knitted and woven fabrics, respectively.

Table 4.21 Ideal Dyeing Combination for Knitted Fabric for pH Level Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - SUPPLIER 1																	
pH Trials:							KNITTED										
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub		
									Face	Back	Face	Back	Face	Back	Face	Back	
3	8	5	9	80	7	1:20	12.2	4/5	5	4/5	5	5	4	4	4	4/5	

Table 4.22 Ideal Dyeing Combination for Woven Fabric for pH Level Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - SUPPLIER 1																
pH Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
3	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4

4.3.2.3. SUPPLIERS 1 AND 2 (DYEING SEQUENCE 2)

4.3.2.3.1. Knitted Fabric Results

The K/S for Suppliers 1 and 2 is represented in Figure 4.22, with the highest K/S seen at a pH of 5, for Supplier 2. All dyeing combinations for Supplier 1, show a decrease in K/S at each pH level, as the level of the remaining parameters are increased, whereas Supplier 2 only exhibits this trend at pH of 5 and 6. Furthermore, all dyeing combinations for Supplier 1 show a decrease in K/S as the pH is increased from 3 to 5 to 6, with Supplier 2 showing the same for dyeing combinations 2 and 3.

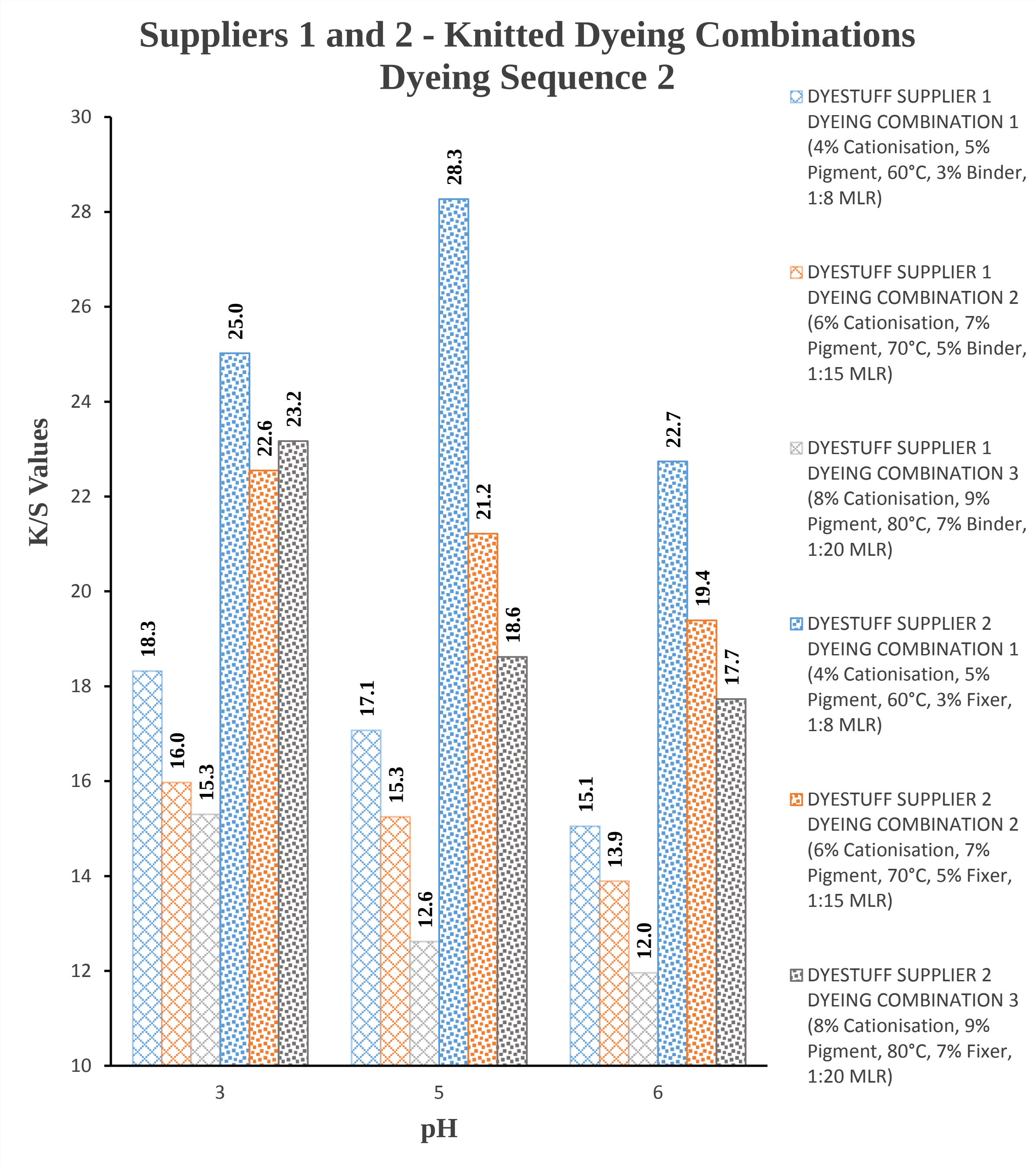


Figure 4.22 Effect of pH Level on K/S for the Dyeing Combinations for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

Table 4.23, shows that Supplier 1 did not achieve acceptable pass ratings of 3/4 for pH at all dyeing combinations, whereas Supplier 2 did at a pH of 3 and 5 for dyeing combination 1, and at a pH of 3 for dyeing combination 3. In addition, Figure 4.23 shows the dyeing combinations that have passed on all fastness with a rating of 3/4. Accordingly, only dyestuff Supplier 2 passed in terms of all the fastness criteria at a pH of 3 and 5, with the corresponding K/S values being much higher than that for Supplier 1.

Table 4.23 Knitted Test Results for pH Level Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
pH Trials:							KNITTED										Dyeing Combination Averages	Total pH Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	18.3	5	4	4	4	4	2/3	2/3	2/3	3	17.7	15.0
	4	5	5	60	3	1:8	17.1	4/5	4	4	4	4	2/3	2/3	2	2		
	4	6	5	60	3	1:8	15.1	4/5	4/5	4/5	4/5	4/5	3	3	2/3	3		
2	6	3	7	70	5	1:15	16.0	4/5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3	15.4	
	6	5	7	70	5	1:15	15.3	5	4/5	4/5	4/5	4/5	3/4	3	3	3		
	6	6	7	70	5	1:15	13.9	5	4/5	4/5	4/5	4/5	2	3	2/3	2/3		
3	8	3	9	80	7	1:20	15.3	5	4/5	4/5	4/5	4/5	3/4	3	3	3/4	13.9	
	8	5	9	80	7	1:20	12.6	5	4/5	4/5	4/5	4/5	3	3	3	3		
	8	6	9	80	7	1:20	12.0	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3		
SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
pH Trials:							KNITTED										Dyeing Combination Averages	Total pH Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.0	5	4/5	5	5	5	3/4	4	4	4	25.3	21.7
	4	5	5	60	3	1:8	28.3	5	5	5	5	5	4/5	4	4	4/5		
	4	6	5	60	3	1:8	22.7	5	5	5	5	5	4	4/5	3	4		
2	6	3	7	70	5	1:15	22.6	5	4/5	4/5	4/5	4/5	3	2/3	3	3	21.1	
	6	5	7	70	5	1:15	21.2	5	4	4	4/5	4/5	2/3	2/3	2	3		
	6	6	7	70	5	1:15	19.4	5	5	4/5	4/5	4/5	3	2/3	3	3		
3	8	3	9	80	7	1:20	23.2	5	5	5	5	5	4	3/4	3/4	3/4	19.8	
	8	5	9	80	7	1:20	18.6	5	4	4	4	4	2/3	2/3	3	3		
	8	6	9	80	7	1:20	17.7	5	4/5	4/5	5	4/5	2/3	2	2	2/3		

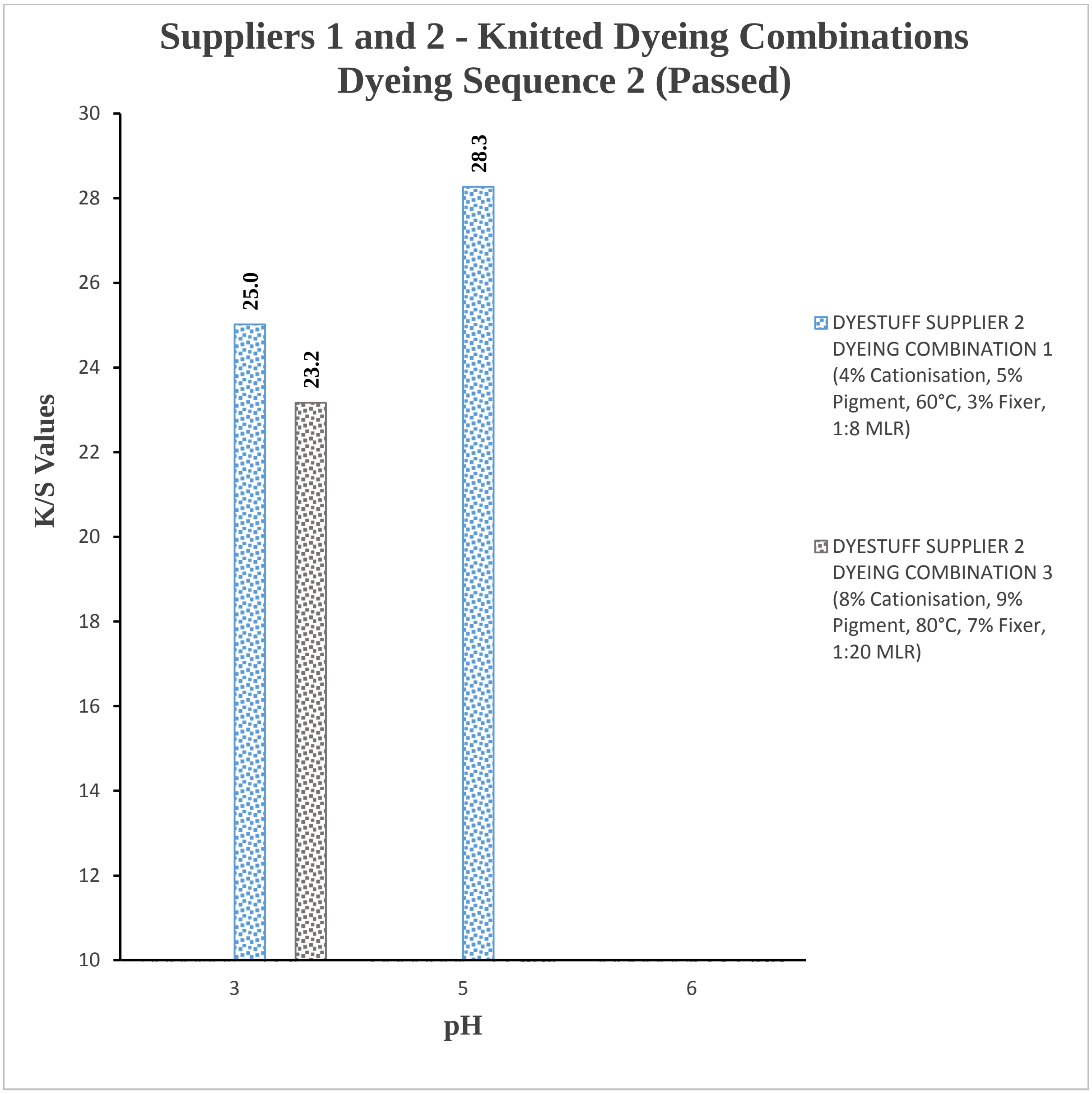


Figure 4.23 Grey Scale Ratings of 3/4 or Higher for pH Level Trials for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

4.3.2.3.2. Woven Fabric Results

The K/S for Suppliers 1 and 2, is represented in Figure 4.24, with the highest K/S seen at pH 5 for dyeing sequence 2. All dyeing combinations for Supplier 2, show a decrease in K/S at each pH level, as the level of the remaining parameters are increased, with Supplier 1 exhibiting the same trend at pH of 5 and 6. A decrease in K/S is also visible for all dyeing combinations for Supplier 1, and dyeing combinations 2 and 3 for Supplier 2, as the pH is increased from 3 to 5 to 6.

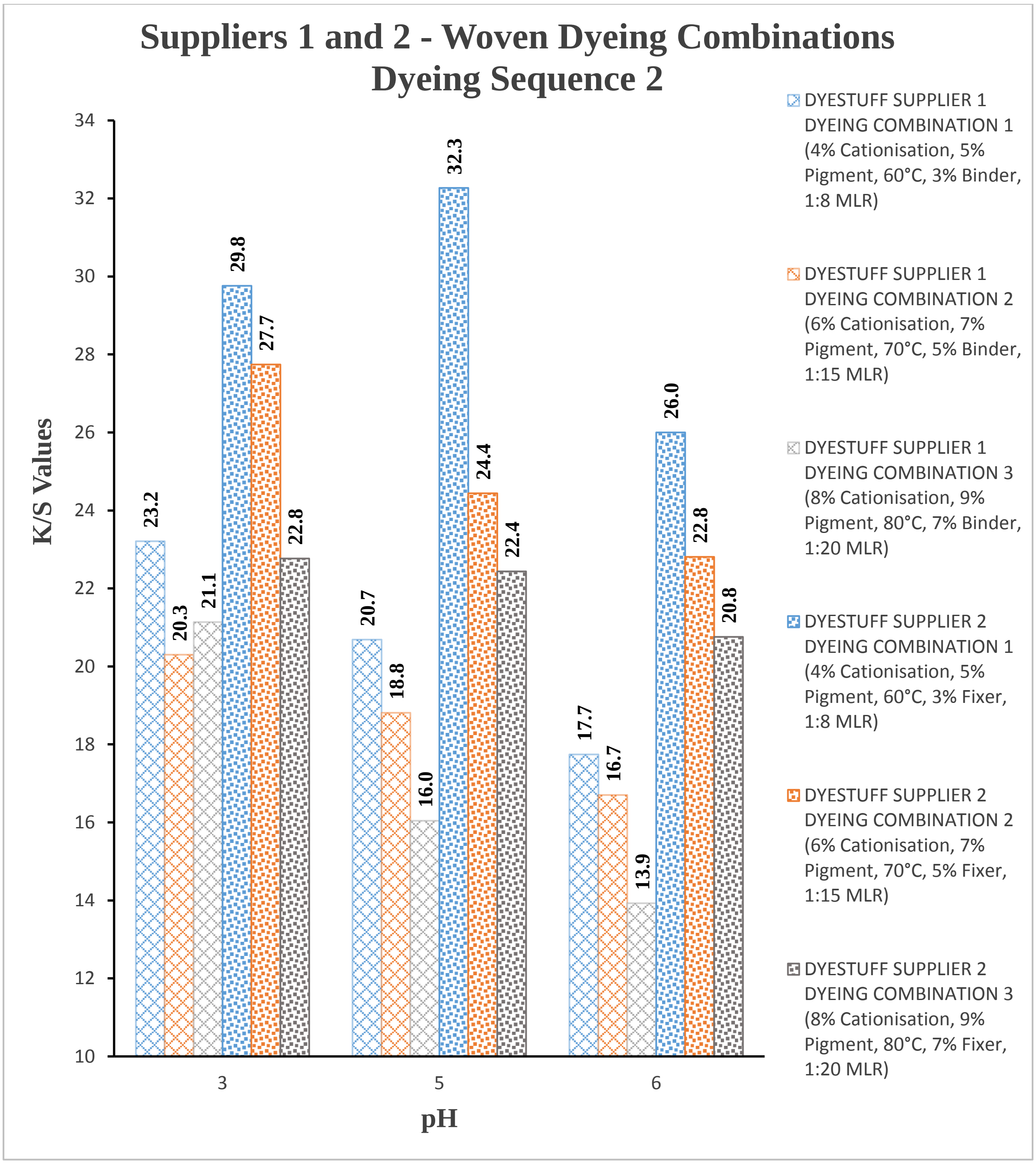


Figure 4.24 Effect of pH Level on K/S for the Dyeing Combinations for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

Table 4.24, shows that Supplier 1 achieves acceptable pass ratings of 3/4 at a pH of 3 for dyeing combinations 2 and 3, whereas Supplier 2 achieves the same at pH of 3 and 5 for dyeing combination 1, and at a pH of 3 for dyeing combination 3. In addition, Figure 4.25 shows the dyeing combinations that have passed on all fastness criteria, with the corresponding K/S values for Supplier 2 being much higher than that for Supplier 2.

Table 4.24 Woven Test Results for pH Level Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
pH Trials:							WOVEN										Dyeing Combination Averages	Total pH Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	23.2	5	4/5	4/5	4/5	4/5	3	3	3	3	20.5	18.2
	4	5	5	60	3	1:8	20.7	4/5	4	4	4	4	3	2/3	2/3	2		
	4	6	5	60	3	1:8	17.7	5	4/5	4/5	4/5	4/5	3	3	3/4	3/4		
2	6	3	7	70	5	1:15	20.3	5	4/5	5	5	4/5	4/5	4	3/4	4	18.6	
	6	5	7	70	5	1:15	18.8	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3/4		
	6	6	7	70	5	1:15	16.7	5	4/5	4/5	5	5	3	3	2/3	2/3		
3	8	3	9	80	7	1:20	21.1	5	4/5	5	5	5	4	4	4/5	4	17.0	
	8	5	9	80	7	1:20	16.0	4/5	5	5	4/5	4/5	3	3	3/4	3/4		
	8	6	9	80	7	1:20	13.9	4/5	4/5	4/5	4/5	4/5	3/4	3	3	3		
SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
pH Trials:							WOVEN										Dyeing Combination Averages	Total pH Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	29.8	5	5	5	5	5	4	4	3/4	3/4	29.3	24.9
	4	5	5	60	3	1:8	32.3	5	5	5	5	5	4/5	4/5	4/5	4		
	4	6	5	60	3	1:8	26.0	5	5	5	5	5	3	4	4	3		
2	6	3	7	70	5	1:15	27.7	5	4/5	4/5	4/5	4/5	3	4	3	3	25.0	
	6	5	7	70	5	1:15	24.4	5	5	5	5	5	3/4	3	3	4		
	6	6	7	70	5	1:15	22.8	5	5	5	5	5	4	3	3	2/3		
3	8	3	9	80	7	1:20	22.8	5	5	5	5	5	3/4	3/4	4	4	22.0	
	8	5	9	80	7	1:20	22.4	5	4/5	4/5	4/5	4/5	4	4	3/4	3		
	8	6	9	80	7	1:20	20.8	5	5	5	5	5	3	3	3	2		

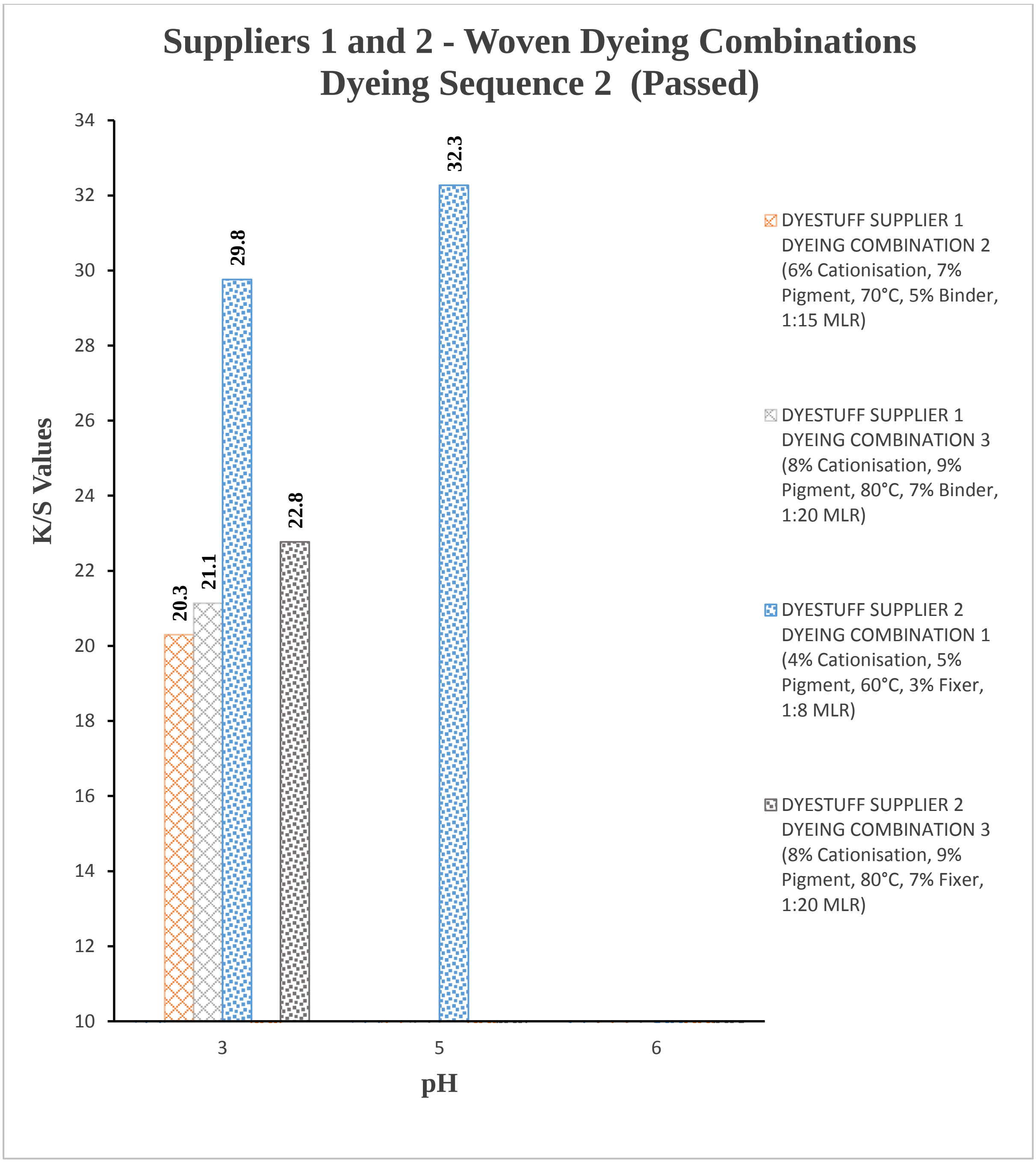


Figure 4.25 Grey Scale Ratings of 3/4 or Higher for pH Level Trials for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

4.3.2.4. <u>DISCUSSION</u>

Supplier 2 obtained a higher K/S for both the knitted and woven fabrics, than that for Supplier 1, with acceptable pass ratings of 3/4, as indicated in Figures 4.23 and 4.25, respectively, which shows that only Supplier 2, obtained a pass at pH of 3 and 5, for both the knitted and woven fabric, while Supplier 1 only achieves a pass for the woven fabric at a pH of 3. In addition, only one dyeing combination each, for the knitted and woven fabric for Supplier 2, and one dyeing combination for the woven fabric for Supplier 1, achieved pass ratings of 4 or higher for all fastness. Tables 4.25 and 4.26, represents the knitted and woven dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the only choice for knitted being K/S of 28.3 and woven higher at 32.3, both at a pH of 5 for dyeing combination 1, sequence 2, Supplier 2.

Table 4.25 Ideal Dyeing Combinations for Knitted Fabric for pH Level Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - SUPPLIER 2																
pH Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	5	5	60	3	1:8	28.3	5	5	5	5	5	4/5	4	4	4/5

Table 4.26 Ideal Dyeing Combinations for Woven Fabric for pH Level Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - SUPPLIER 1																
pH Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
3	8	3	9	80	7	1:20	21.1	5	4/5	5	5	5	4	4	4/5	4
SEQUENCE 2 - SUPPLIER 2																
pH Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	5	5	60	3	1:8	32.3	5	5	5	5	5	4/5	4/5	4/5	4

4.3.2.5. SUPPLIER 1 (DYEING SEQUENCE 1 AND 2)

4.3.2.5.1. Knitted Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.26, with the highest K/S seen at pH 5 for dyeing sequence 1. All dyeing combinations, for dyeing sequence 1, show a decrease in K/S at pH of 5 and 6, with the same observed for dyeing sequence 2 at all pH levels. Dyeing combination 3 for sequence 1, as well as all dyeing combinations for sequence 2, show a decrease in K/S as the pH level is increased from 3 to 5 to 6.

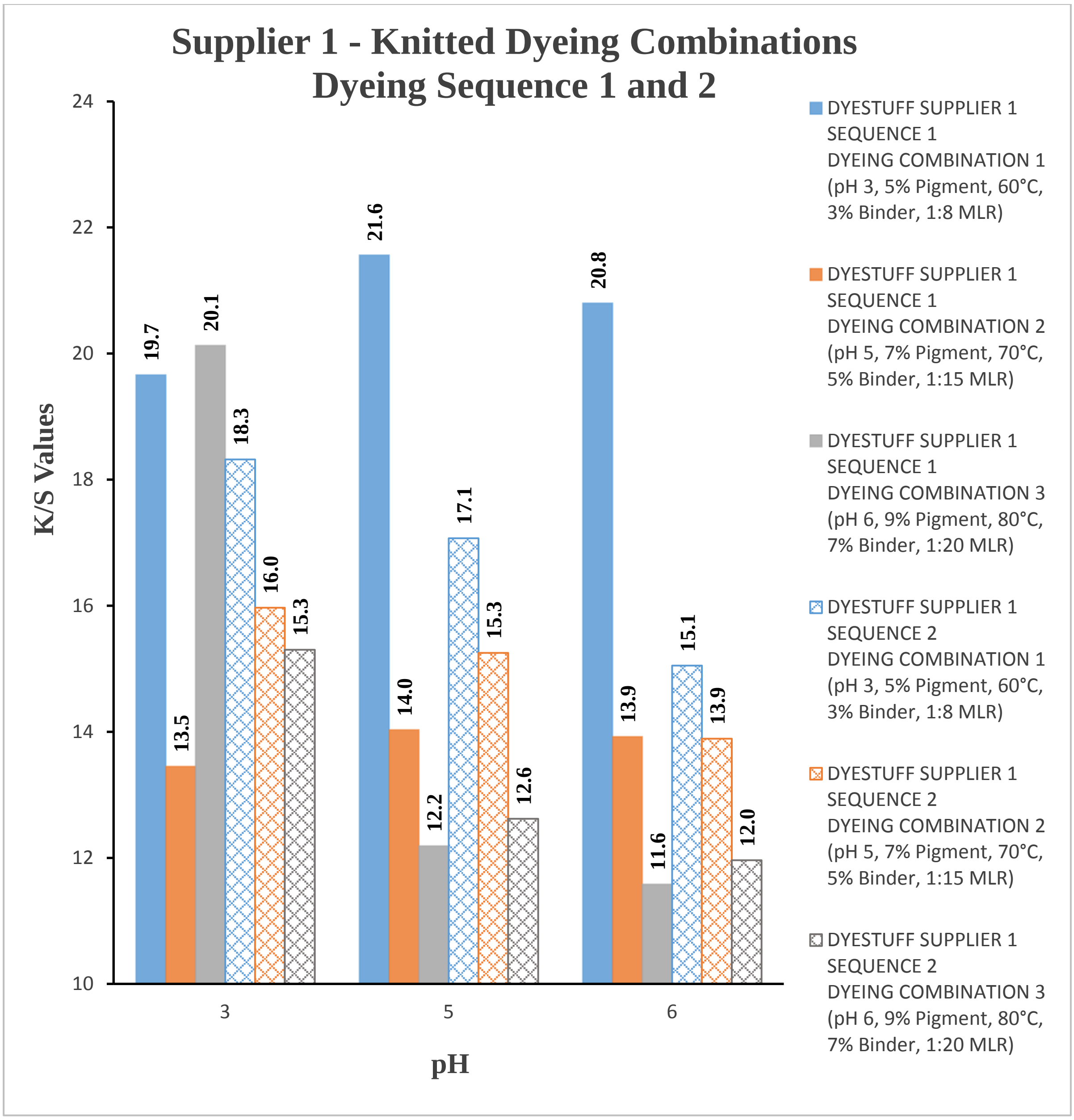


Figure 4.26 Effect of pH Level on K/S for the Dyeing Combinations for Knitted Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

Table 4.27 shows that sequence 1 achieves an acceptable pass rating of 3/4 at pH of 6 for dyeing combination 1, and at pH of 3 and 5 for dyeing combination 2, as well as at all pH levels for dyeing combination 3. Sequence 2, however, did not achieve acceptable pass ratings at any levels of pH for all dyeing combinations. In addition, Figure 4.27 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, only sequence 1 achieves a pass at all levels of pH, with K/S values higher than that of sequence 2.

Table 4.27 Knitted Test Results for pH Level Trials for Supplier 1, Dyeing Sequence 1 and 2

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
pH Trials:							KNITTED										Dyeing Combination Averages	Total pH Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub Face	Warp Dry Rub Back	Weft Dry Rub Face	Weft Dry Rub Back	Warp Wet Rub Face	Warp Wet Rub Back	Weft Wet Rub Face	Weft Wet Rub Back		
1	4	3	5	60	3	1:8	19.7	4/5	3/4	4/5	3	3/4	2/3	2/3	2	2/3	20.6	16.4
	4	5	5	60	3	1:8	21.6	4/5	4/5	4/5	4/5	4/5	3	3	3	3		
	4	6	5	60	3	1:8	20.8	4/5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	4		
2	6	3	7	70	5	1:15	13.5	4/5	4/5	4	4/5	4/5	3/4	3/4	3/4	3/4	16.1	
	6	5	7	70	5	1:15	14.0	5	4/5	4/5	4/5	4/5	4	3/4	4	4		
	6	6	7	70	5	1:15	13.9	4/5	4/5	4	4	4/5	3/4	3	3/4	3/4		
3	8	3	9	80	7	1:20	20.1	4/5	5	4/5	4/5	4/5	4	3/4	3/4	3/4	15.4	
	8	5	9	80	7	1:20	12.2	4/5	5	4/5	5	5	4	4	4	4/5		
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4		
SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
pH Trials:							KNITTED										Dyeing Combination Averages	Total pH Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub Face	Warp Dry Rub Back	Weft Dry Rub Face	Weft Dry Rub Back	Warp Wet Rub Face	Warp Wet Rub Back	Weft Wet Rub Face	Weft Wet Rub Back		
1	4	3	5	60	3	1:8	18.3	5	4	4	4	4	2/3	2/3	2/3	3	17.7	15.0
	4	5	5	60	3	1:8	17.1	4/5	4	4	4	4	2/3	2/3	2	2		
	4	6	5	60	3	1:8	15.1	4/5	4/5	4/5	4/5	4/5	3	3	2/3	3		
2	6	3	7	70	5	1:15	16.0	4/5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3	15.4	
	6	5	7	70	5	1:15	15.3	5	4/5	4/5	4/5	4/5	3/4	3	3	3		
	6	6	7	70	5	1:15	13.9	5	4/5	4/5	4/5	4/5	2	3	2/3	2/3		
3	8	3	9	80	7	1:20	15.3	5	4/5	4/5	4/5	4/5	3/4	3	3	3/4	13.9	
	8	5	9	80	7	1:20	12.6	5	4/5	4/5	4/5	4/5	3	3	3	3		
	8	6	9	80	7	1:20	12.0	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3		

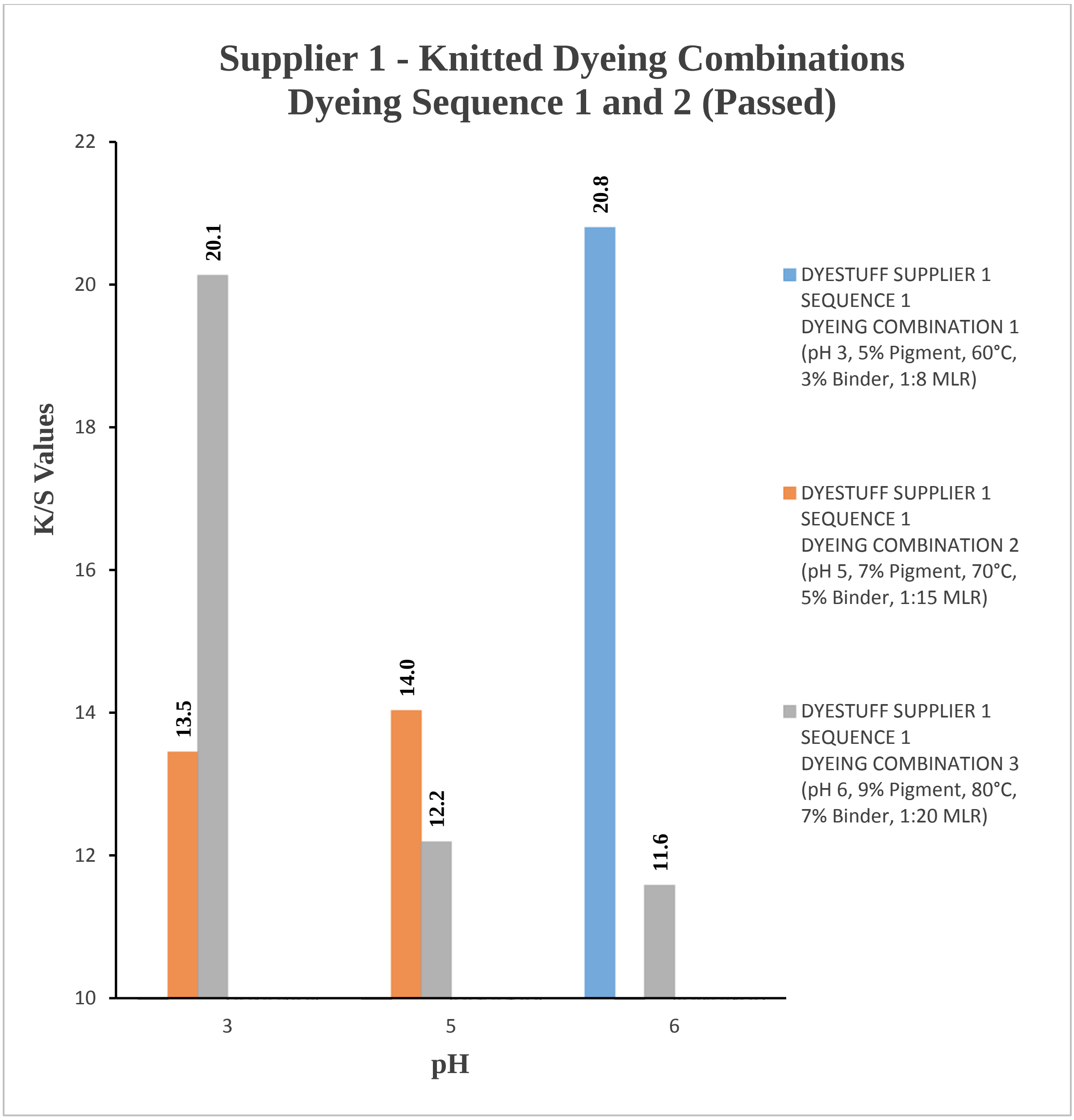


Figure 4.27 Grey Scale Ratings of 3/4 or Higher for pH Level Trials for Knitted Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

4.3.2.5.2. Woven Fabric Results

The K/S for dyeing sequence 1 and 2, is represented in Figure 4.28, with the highest K/S seen at pH of 5 for dyeing sequence 1. All dyeing combinations, for dyeing sequence 1, show a decrease in K/S at each level of pH, as the level of the remaining parameters are increased. Sequence 2, for all dyeing combinations, show a decreased in K/S as pH increases from 3 to 5 to 6. The same trend is observed for dyeing combinations 2 and 3, for dyeing sequence 1.

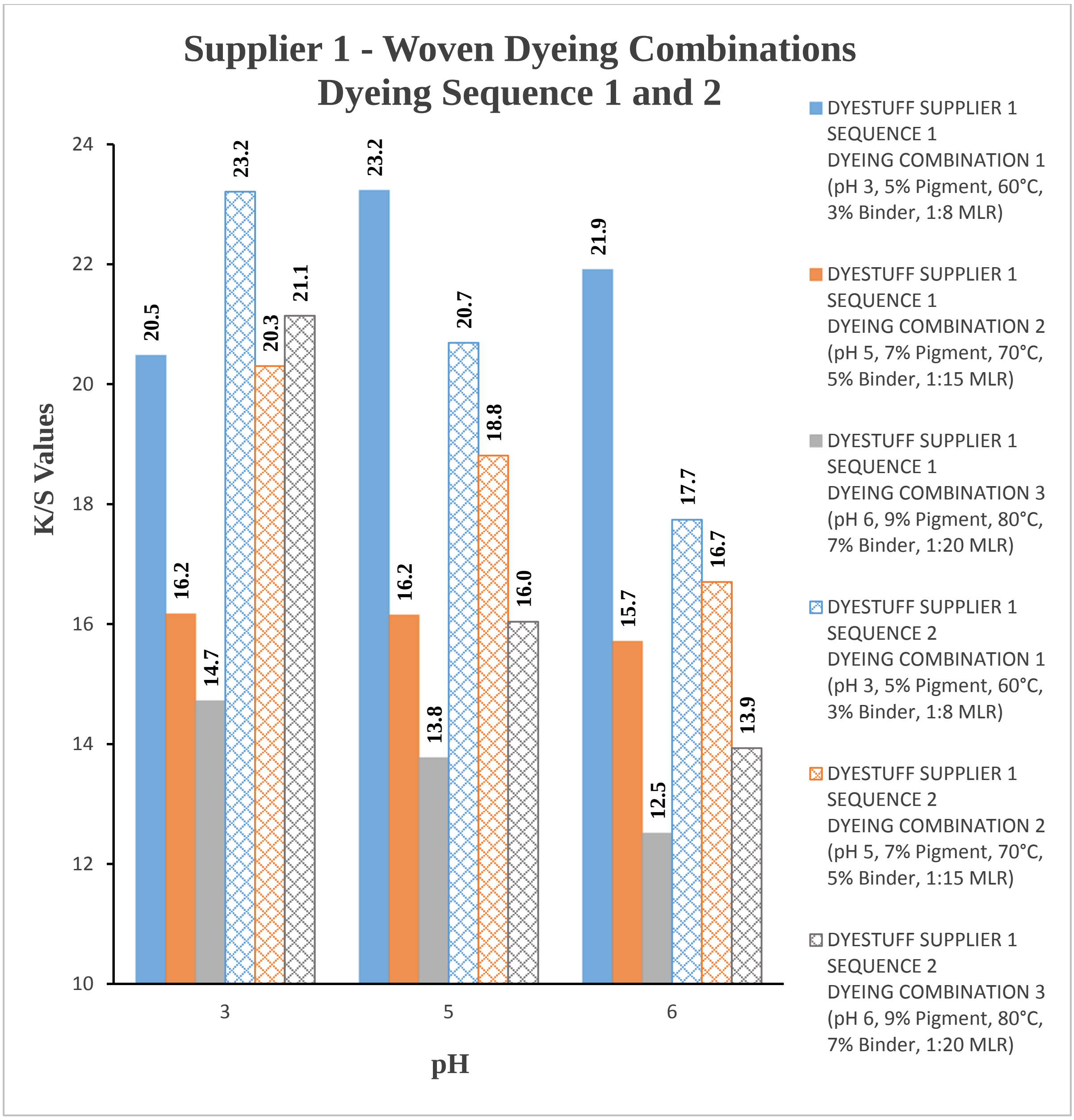


Figure 4.28 Effect of pH Level on K/S for the Dyeing Combinations for Woven Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

Table 4.28, shows that sequence 1 achieves an acceptable pass rating of 3/4 at pH of 3 and 5 for dyeing combinations 1 and 2, as well as at all pH levels for dyeing combination 3; whereas sequence 2, achieves acceptable pass ratings at pH of 5 and 6 for dyeing combination 1. In addition, Figure 4.29 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, sequence 1 achieves a pass at all levels of pH, with the highest K/S.

Table 4.28 Woven Test Results for pH Level Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
pH Trials:							WOVEN										Dyeing Combination Averages	Total pH Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	20.5	4/5	4/5	4/5	4/5	4/5	4	4/5	3/4	4	21.9	16.8
	4	5	5	60	3	1:8	23.2	4/5	4/5	4/5	4/5	4/5	3/4	4	3/4	3/4		
	4	6	5	60	3	1:8	21.9	4/5	4/5	4/5	4/5	4	3/4	3/4	3	3		
2	6	3	7	70	5	1:15	16.2	4/5	4	4/5	4/5	4	3/4	4	3/4	4	16.0	
	6	5	7	70	5	1:15	16.2	5	4/5	4/5	4/5	4/5	4/5	4/5	4	3/4		
	6	6	7	70	5	1:15	15.7	4/5	4/5	4/5	4	4/5	3/4	3/4	3	3/4		
3	8	3	9	80	7	1:20	14.7	4/5	4/5	4/5	4/5	5	4	4	3/4	4	13.7	
	8	5	9	80	7	1:20	13.8	4/5	5	4/5	5	4/5	4	4	3/4	3/4		
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4		
SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
pH Trials:							WOVEN										Dyeing Combination Averages	Total pH Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	23.2	5	4/5	4/5	4/5	4/5	3	3	3	3	20.5	18.2
	4	5	5	60	3	1:8	20.7	4/5	4	4	4	4	3	2/3	2/3	2		
	4	6	5	60	3	1:8	17.7	5	4/5	4/5	4/5	4/5	3	3	3/4	3/4		
2	6	3	7	70	5	1:15	20.3	5	4/5	5	5	4/5	4/5	4	3/4	4	18.6	
	6	5	7	70	5	1:15	18.8	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3/4		
	6	6	7	70	5	1:15	16.7	5	4/5	4/5	5	5	3	3	2/3	2/3		
3	8	3	9	80	7	1:20	21.1	5	4/5	5	5	5	4	4	4/5	4	17.0	
	8	5	9	80	7	1:20	16.0	4/5	5	5	4/5	4/5	3	3	3/4	3/4		
	8	6	9	80	7	1:20	13.9	4/5	4/5	4/5	4/5	4/5	3/4	3	3	3		

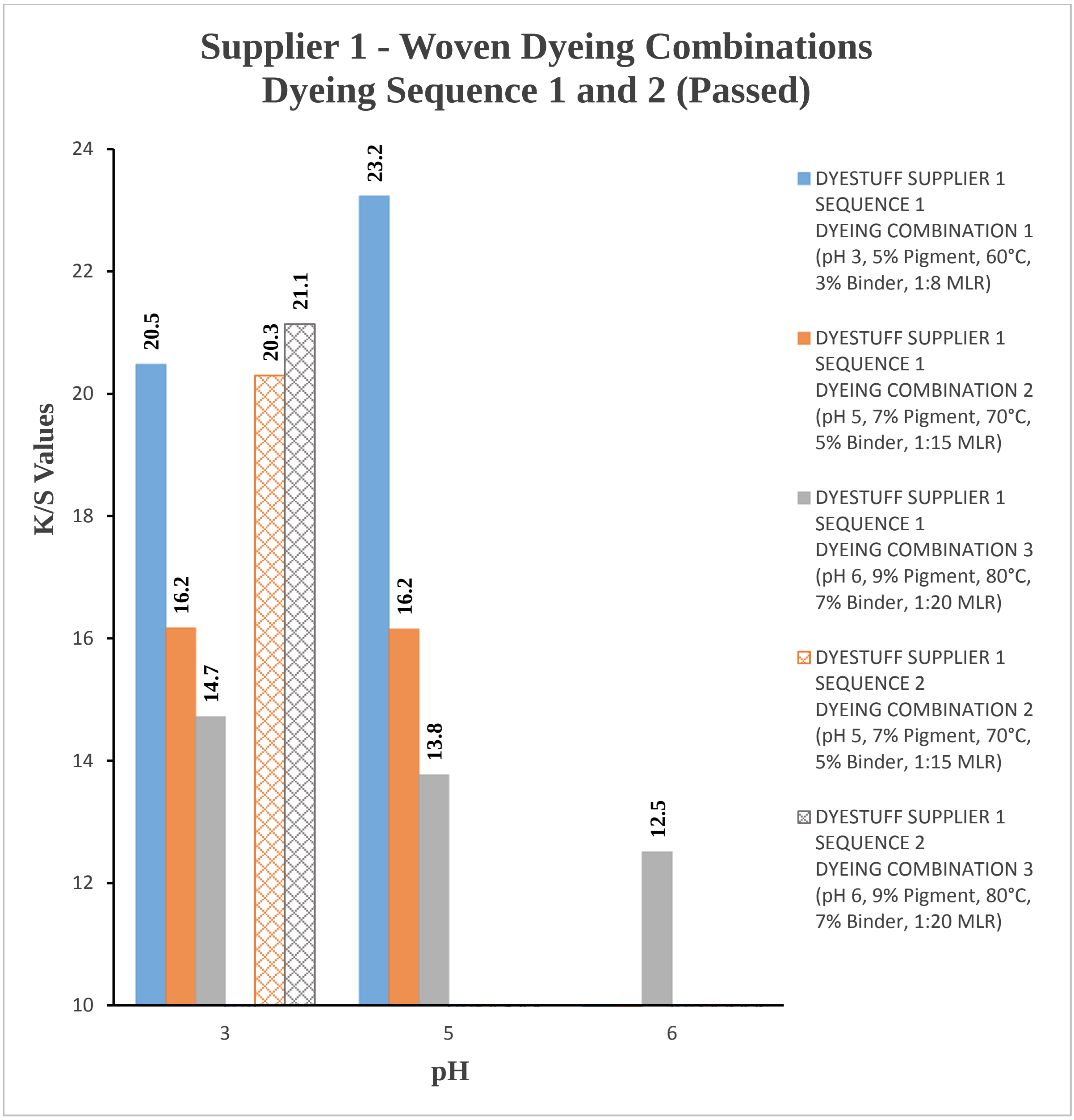


Figure 4.29 Grey Scale Ratings of 3/4 or Higher for pH Level Trials for Woven Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

4.3.2.6. <u>DISCUSSION</u>

Acceptable pass ratings of 3/4, as indicated in Figures 4.27 and 4.29, showed that sequence 1 obtained pass ratings at all pH levels for both the knitted and woven fabrics, while sequence 2 only obtained a pass rating for the woven fabric at pH of 3. In addition, 2 dyeing combinations for the knitted fabric and 1 for the woven fabric, achieved pass ratings of 4 or higher for all fastness criteria, for sequence 1. Tables 4.29 and 4.30, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for knitted being K/S of 12.2

at pH of 5, with the woven having a K/S of 12.5 at pH of 6, both for dyeing combination 3, sequence 1, Supplier 1.

Table 4.29 Ideal Dyeing Combinations for Knitted Fabric for pH Level Trails for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 1																		
pH Trials:							KNITTED											
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
3	8	5	9	80	7	1:20	12.2	4/5	5	4/5	5	5	4	4	4	4/5		
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4		

Table 4.30 Ideal Dyeing Combinations for Woven Fabric for pH Level Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 1																
pH Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
3	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4

4.3.2.7. SUPPLIER 2 (DYEING SEQUENCE 1 AND 2)

4.3.2.7.1. Knitted Fabric Results

The K/S for Supplier 2, for dyeing sequence 1 and 2, is represented in Figure 4.30, with the highest K/S seen at pH of 5 for dyeing sequence 2. All dyeing combinations, for dyeing sequence 1, show a decrease in K/S at pH of 3 and 5, with the same observed for dyeing sequence 2 at pH of 5 and 6. However, a clear trend is visible for dyeing sequence 2, where dyeing combinations 2 and 3 show a decrease in K/S as the pH levels are increased from 3 to 5 to 6.

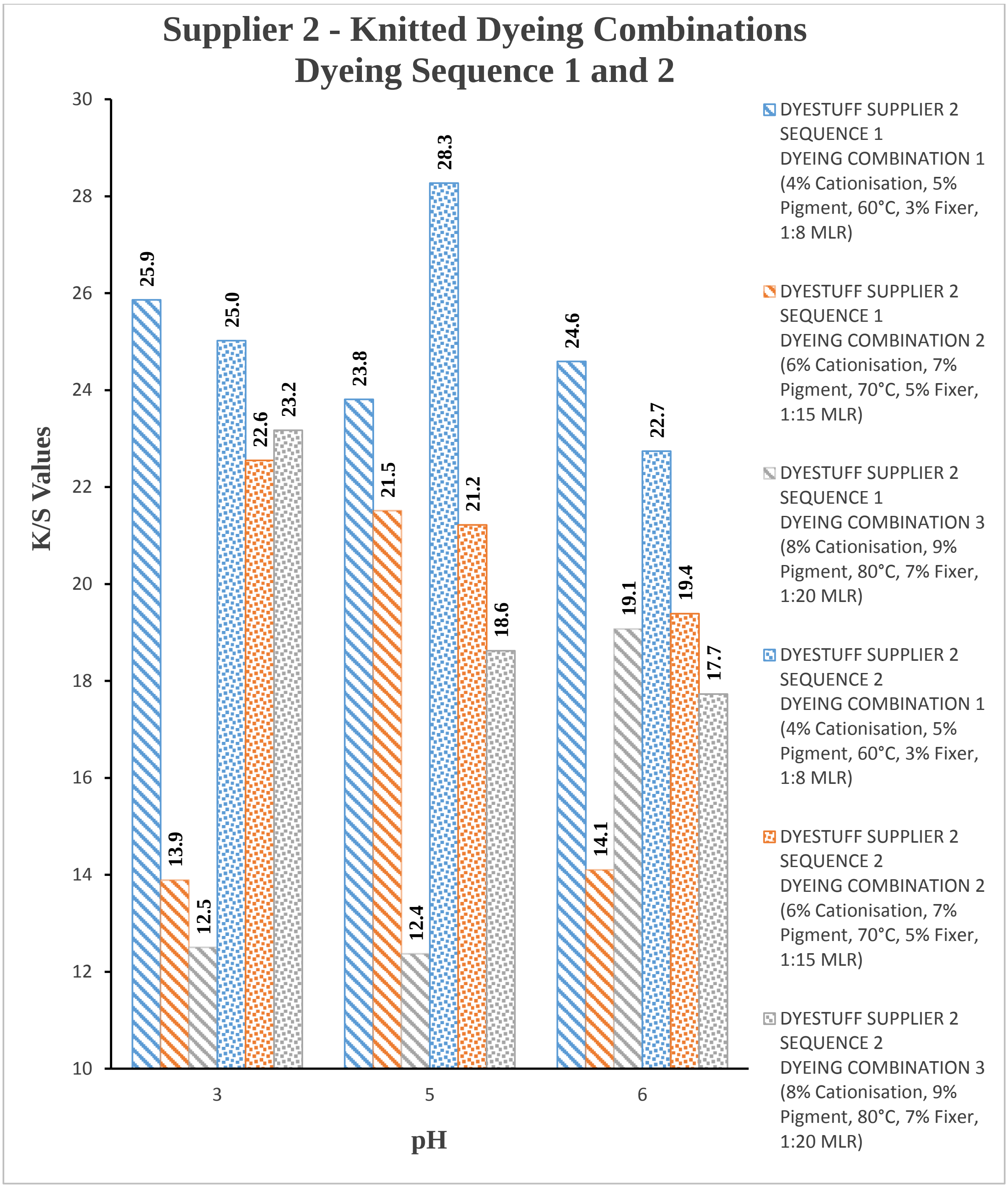


Figure 4.30 Effect of pH Level on K/S for the Dyeing Combinations for Knitted Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

Table 4.31, shows that sequence 1 does not achieve acceptable pass ratings of 3/4 for all 3 dyeing combinations. Sequence 2, however, achieves acceptable pass ratings at pH of 3 and 5 for dyeing combination 1, and at pH of 3 for dyeing combination 3. In addition, Figure 4.31 shows the dyeing combinations that have passed on all fastness with a rating of 3/4. Accordingly, only sequence 2 achieves a pass at pH of 3 and 5, with the highest K/S.

Table 4.31 Knitted Test Results for pH Levels Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
pH Trials:							KNITTED										Dyeing Combination Averages	Total pH Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.9	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3	24.8	17.7
	4	5	5	60	3	1:8	23.8	5	5	5	4/5	4/5	2/3	3	2	2/3		
	4	6	5	60	3	1:8	24.6	5	4/5	4/5	4/5	4/5	2/3	2/3	2	2/3		
2	6	3	7	70	5	1:15	13.9	5	4/5	4/5	4/5	4/5	3	3	3	3	16.5	
	6	5	7	70	5	1:15	21.5	5	4/5	5	5	4/5	3/4	3	3	3		
	6	6	7	70	5	1:15	14.1	4/5	4/5	4/5	4/5	4/5	2/3	2/3	2/3	2/3		
3	8	3	9	80	7	1:20	12.5	5	5	5	5	5	3	3	3/4	4	14.6	
	8	5	9	80	7	1:20	12.4	5	4/5	4/5	4/5	4/5	2	1/2	3	2/3		
	8	6	9	80	7	1:20	19.1	5	4/5	4/5	5	5	2/3	2/3	2/3	3		
SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
pH Trials:							KNITTED										Dyeing Combination Averages	Total pH Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.0	5	4/5	5	5	5	3/4	4	4	4	25.3	21.7
	4	5	5	60	3	1:8	28.3	5	5	5	5	5	4/5	4	4	4/5		
	4	6	5	60	3	1:8	22.7	5	5	5	5	5	4	4/5	3	4		
2	6	3	7	70	5	1:15	22.6	5	4/5	4/5	4/5	4/5	3	2/3	3	3	21.1	
	6	5	7	70	5	1:15	21.2	5	4	4	4/5	4/5	2/3	2/3	2	3		
	6	6	7	70	5	1:15	19.4	5	5	4/5	4/5	4/5	3	2/3	3	3		
3	8	3	9	80	7	1:20	23.2	5	5	5	5	5	4	3/4	3/4	3/4	19.8	
	8	5	9	80	7	1:20	18.6	5	4	4	4	4	2/3	2/3	3	3		
	8	6	9	80	7	1:20	17.7	5	4/5	4/5	5	4/5	2/3	2	2	2/3		

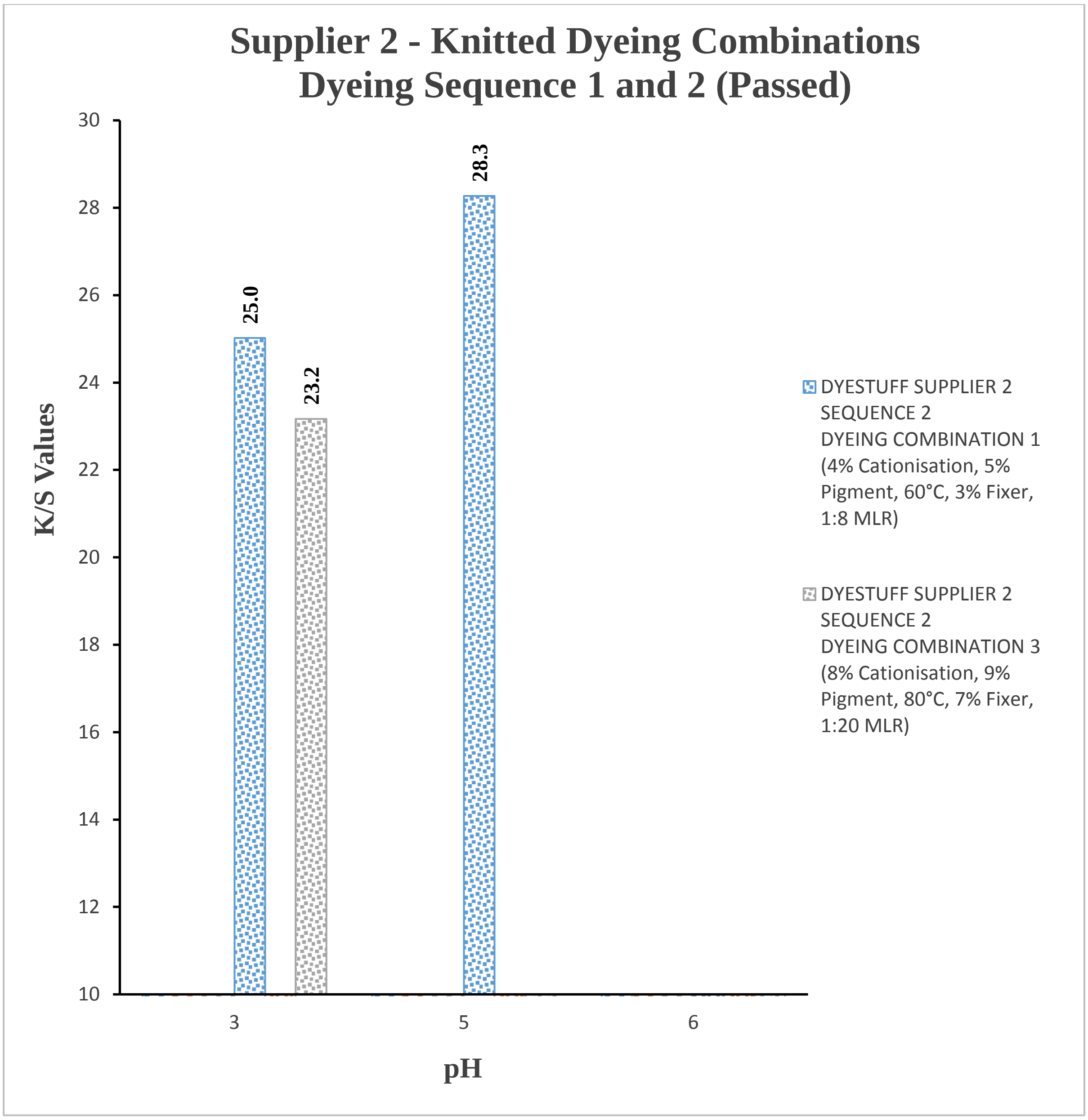


Figure 4.31 Grey Scale Ratings of 3/4 or Higher for pH Level Trials for Knitted Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

4.3.2.7.2. <u>Woven Fabric Results</u>

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.32, with the highest K/S seen at pH of 5 for dyeing sequence 2. All dyeing combinations, for dyeing sequence 1, show a decrease in K/S at pH of 3 and 5, with the same observed for dyeing sequence 2 at all pH levels. Dyeing sequence 1, for dyeing combination 2, shows a decrease in K/S as pH levels are increased from 3 to 5 to 6, with the same observed for dyeing sequence 2, for dyeing combinations 2 and 3.

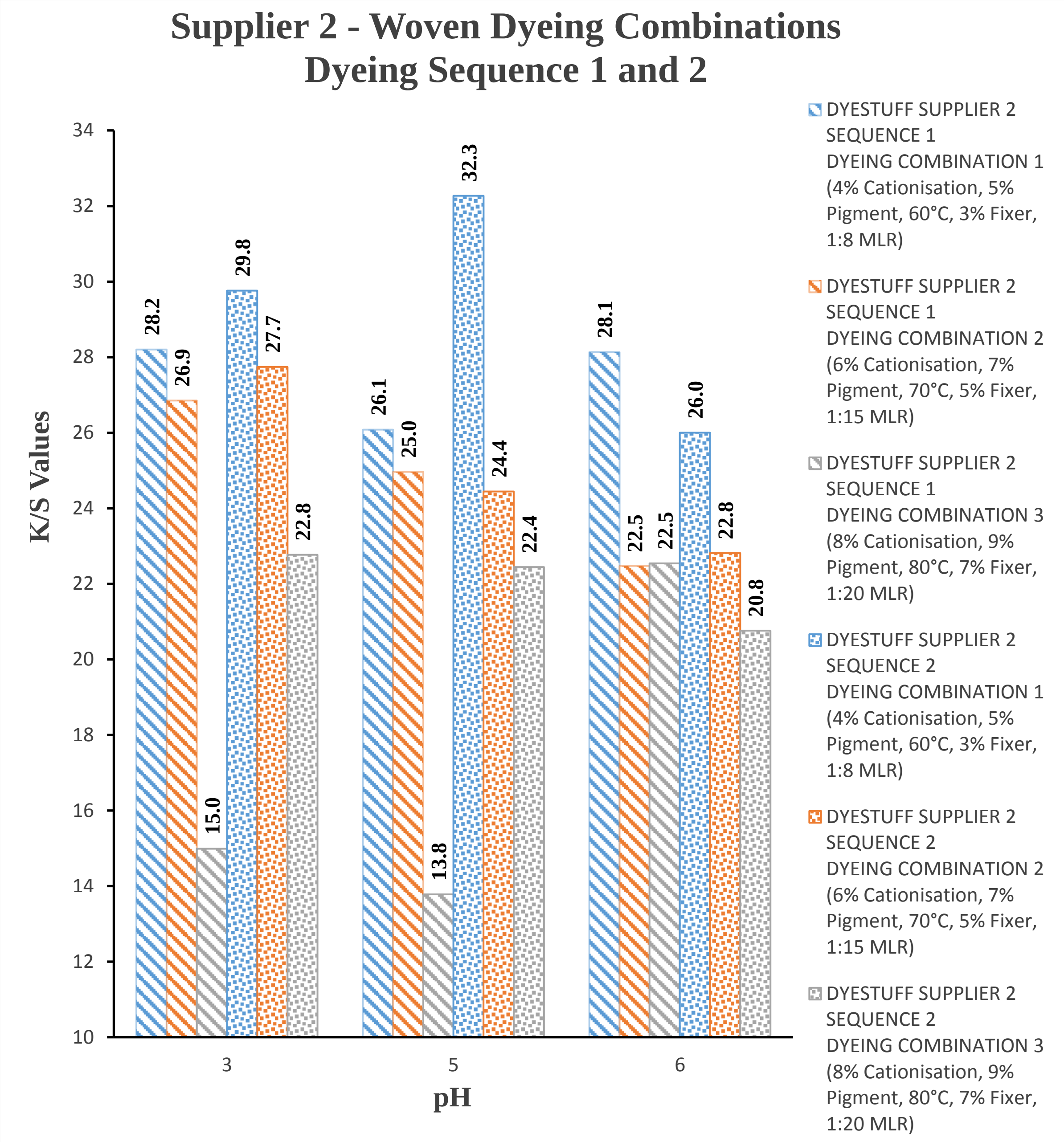


Figure 4.32 Effect of pH Level on K/S for the Dyeing Combinations for Woven Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

Table 4.32, shows that sequence 1 achieves an acceptable pass rating of 3/4 at pH of 3 for dyeing combination 3, while sequence 2, achieves acceptable pass ratings at pH of 3 and 5 for dyeing combination 1, and at pH of 3 for dyeing combination 3. In addition, Figure 4.33 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, dyeing sequence 2 achieves more passes of 3/4 than that for sequence 1, and achieves the highest K/S.

Table 4.32 Woven Test Results for pH Level Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
pH Trials:							WOVEN										Dyeing Combination Averages	Total pH Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub Face	Warp Dry Rub Back	Weft Dry Rub Face	Weft Dry Rub Back	Warp Wet Rub Face	Warp Wet Rub Back	Weft Wet Rub Face	Weft Wet Rub Back		
1	4	3	5	60	3	1:8	28.2	5	4/5	4/5	5	4/5	3	3	3	2/3	27.5	22.5
	4	5	5	60	3	1:8	26.1	5	4/5	4/5	4/5	4/5	3	3	3	2		
	4	6	5	60	3	1:8	28.1	5	5	5	5	5	3	3	3	3		
2	6	3	7	70	5	1:15	26.9	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3/4	24.8	
	6	5	7	70	5	1:15	25.0	5	4/5	4/5	5	4/5	3	3	4	4		
	6	6	7	70	5	1:15	22.5	5	4/5	4/5	4/5	4/5	3	3	3	3		
3	8	3	9	80	7	1:20	15.0	5	4/5	4/5	5	5	4/5	4/5	4	3/4	17.1	
	8	5	9	80	7	1:20	13.8	5	4/5	4/5	5	5	3/4	3	3	2/3		
	8	6	9	80	7	1:20	22.5	5	5	5	5	4/5	3	4	3/4	3		
SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
pH Trials:							WOVEN										Dyeing Combination Averages	Total pH Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub Face	Warp Dry Rub Back	Weft Dry Rub Face	Weft Dry Rub Back	Warp Wet Rub Face	Warp Wet Rub Back	Weft Wet Rub Face	Weft Wet Rub Back		
1	4	3	5	60	3	1:8	29.8	5	5	5	5	5	4	4	3/4	3/4	29.3	24.9
	4	5	5	60	3	1:8	32.3	5	5	5	5	5	4/5	4/5	4/5	4		
	4	6	5	60	3	1:8	26.0	5	5	5	5	5	3	4	4	3		
2	6	3	7	70	5	1:15	27.7	5	4/5	4/5	4/5	4/5	3	4	3	3	25.0	
	6	5	7	70	5	1:15	24.4	5	5	5	5	5	3/4	3	3	4		
	6	6	7	70	5	1:15	22.8	5	5	5	5	5	4	3	3	2/3		
3	8	3	9	80	7	1:20	22.8	5	5	5	5	5	3/4	3/4	4	4	22.0	
	8	5	9	80	7	1:20	22.4	5	4/5	4/5	4/5	4/5	4	4	3/4	3		
	8	6	9	80	7	1:20	20.8	5	5	5	5	5	3	3	3	2		

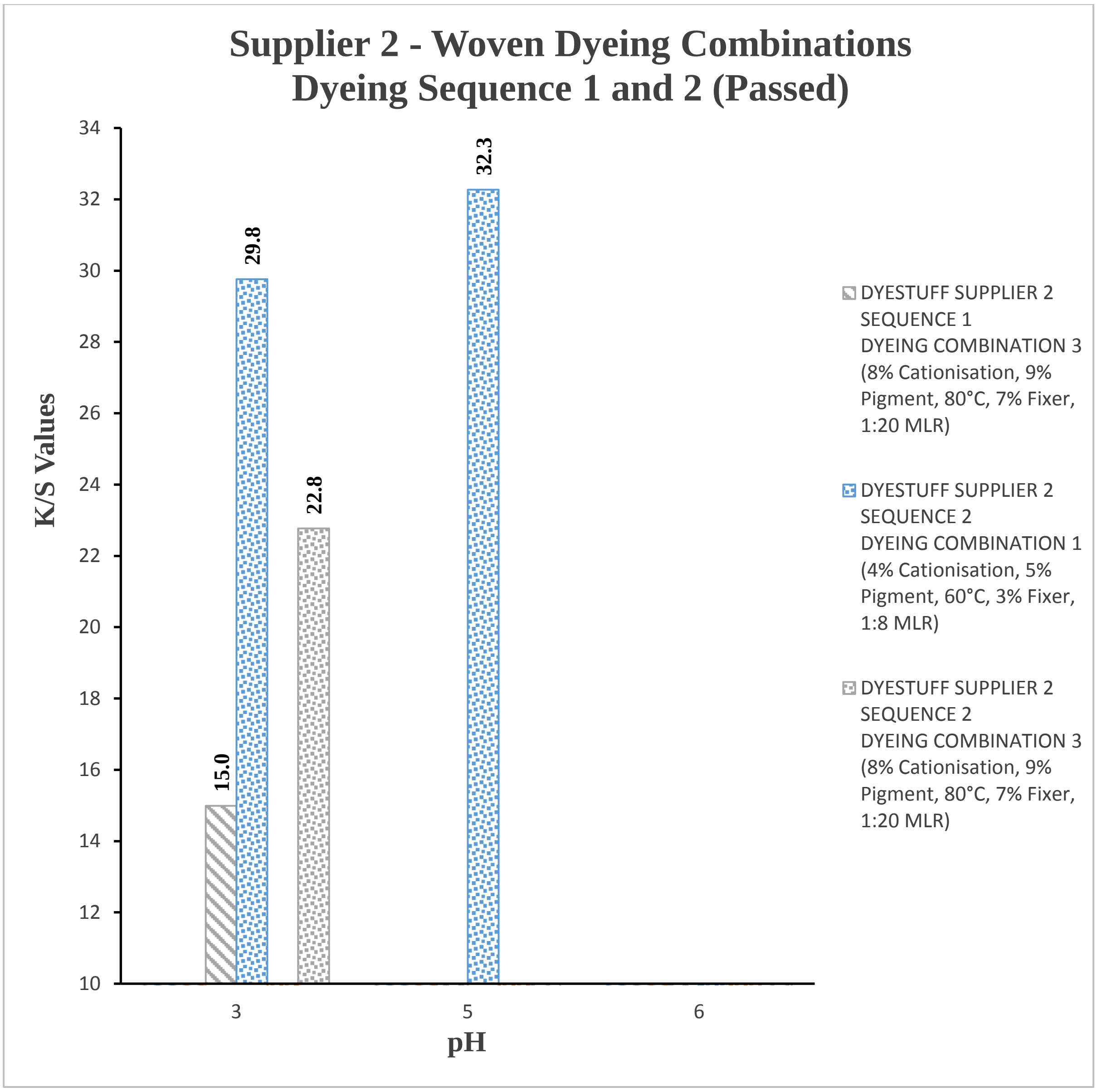


Figure 4.33 Grey Scale Ratings of 3/4 or Higher for pH Level Trials for Woven Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

4.3.2.8. DISCUSSION

Acceptable pass ratings of 3/4, as indicated in Figures 4.31 and 4.33, showed that sequence 1 only achieved a pass for the woven fabric at pH of 3, while sequence 2, for the knitted fabric, obtained pass ratings at pH of 5, with the woven obtaining the same at pH of 3 and 5. In addition, 1 dyeing combination each, for the knitted and woven fabrics, achieved a pass rating of 4 or higher for all fastness criteria, for sequence 2. Tables 4.33 and 4.34, represents the dyeing combination that achieved a Grey Scale rating of 4 or higher, with the only choice for the knitted being K/S of 28.3, and that of the woven being K/S of 32.3, both at pH of 5 for dyeing combination 1, for sequence 2.

Table 4.33 Ideal Dyeing Combination for Knitted Fabric for pH Level Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 2 - SUPPLIER 2																
pH Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	5	5	60	3	1:8	28.27	5	5	5	5	5	4/5	4	4	4/5

Table 4.34 Ideal Dyeing Combination for Woven Fabric for pH Level Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 2 - SUPPLIER 2																
pH Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	5	5	60	3	1:8	32.3	5	5	5	5	5	4/5	4/5	4/5	4

4.3.2.9. <u>CONCLUSION</u>

To conclude the results for all pH level trials for each supplier and sequence, the average K/S was taken into account. The effect of pH on K/S, for both knitted and woven fabrics, for both suppliers and sequences showed a decrease in K/S as the pH level increased from 3 to 5 to 7 for all dyeing combinations, while the remaining 5 parameters (cationisation, pigment, temperature, binder/fixer and MLR) increased in their respective levels.

The knitted fabric for Supplier 1 achieved a higher average K/S for dyeing sequence 1 compared to that for dyeing sequence 2, while for Supplier 2, dyeing sequence 2 obtained a higher K/S compared to that for dyeing sequence 1.

The woven fabric, however, achieved a higher K/S for dyeing sequence 2 compared to that for dyeing sequence 1, for both suppliers. Furthermore, both dyeing sequences for Supplier 2, achieved higher average K/S values compared to that for Supplier 1, for both fabrics. In addition, the K/S values for all woven fabric were higher compared to that for the knitted fabric, with the reasons for this difference being explained in section 4.3.7.

Taking the K/S values into account, it can be concluded that sequence 2 for Supplier 2, achieved the ideal pH level for both the knitted and woven fabric at a pH of 5, with K/S of 28.3 and 32.3, respectively. In addition, these K/S values also achieved Grey Scale ratings of 4 or higher for all fastness criteria. The ideal pH of 5 is also reinforced by previous work carried out by Kumar *et al* (2013), which concluded that a better pigment uptake occurred at pH 5.

4.3.3. Effect of Pigment Concentration

The two dyestuff suppliers were compared with one another to determine the effect of pigment concentration on the outcome of K/S and fastness, when the pigment concentrations were increased from 5 to 7 to 9, while the other 5 parameters (cationisation, pH, temperature, binder/fixer and MLR) were kept constant, per dyeing combination. The pigment concentration trials consisted of three dyeing combinations, with 3 trials per dyeing combination, and were performed using dyeing sequence 1 and 2. The results from these trials for both suppliers and sequences will be concluded in section 4.3.7. The dyeing combinations used in the pigment concentration trials are presented in Table 4.35., with the results presented graphically.

Table 4.35 Dyeing Combinations for Pigment Concentration Trials.

	Pigment Concentration Trials						
	Cationisation (%)	**pH**	**Pigment (%)**	**Temp (°C)**	**Binder/ Fixer (%)**	**MLR**	**Trial No.**
Combination 1	4	3	5	60	3	1:8	1
	4	3	7	60	3	1:8	4
	4	3	9	60	3	1:8	7
Combination 2	6	5	5	70	5	1:15	2
	6	5	7	70	5	1:15	5
	6	5	9	70	5	1:15	8
Combination 3	8	6	5	80	7	1:20	3
	8	6	7	80	7	1:20	6
	8	6	9	80	7	1:20	9

4.3.3.1. <u>SUPPLIERS 1 AND 2 (DYEING SEQUENCE 1)</u>

4.3.3.1.1. Knitted Fabric Results

The K/S for both suppliers is represented in Figure 4.34, which show that the K/S for Supplier 2 is higher than that for Supplier 1. Supplier 1, show a decrease in K/S at 9% pigment, as the levels of the remaining parameters are increased, while Supplier 2 exhibits the same trend at 5% pigment. Furthermore, Supplier 1 shows a decrease in K/S for all dyeing combinations, as the pigment concentration increases from 5 to 7 to 9%, whereas Supplier 2 exhibits the same trend for dyeing combinations 1 and 2.

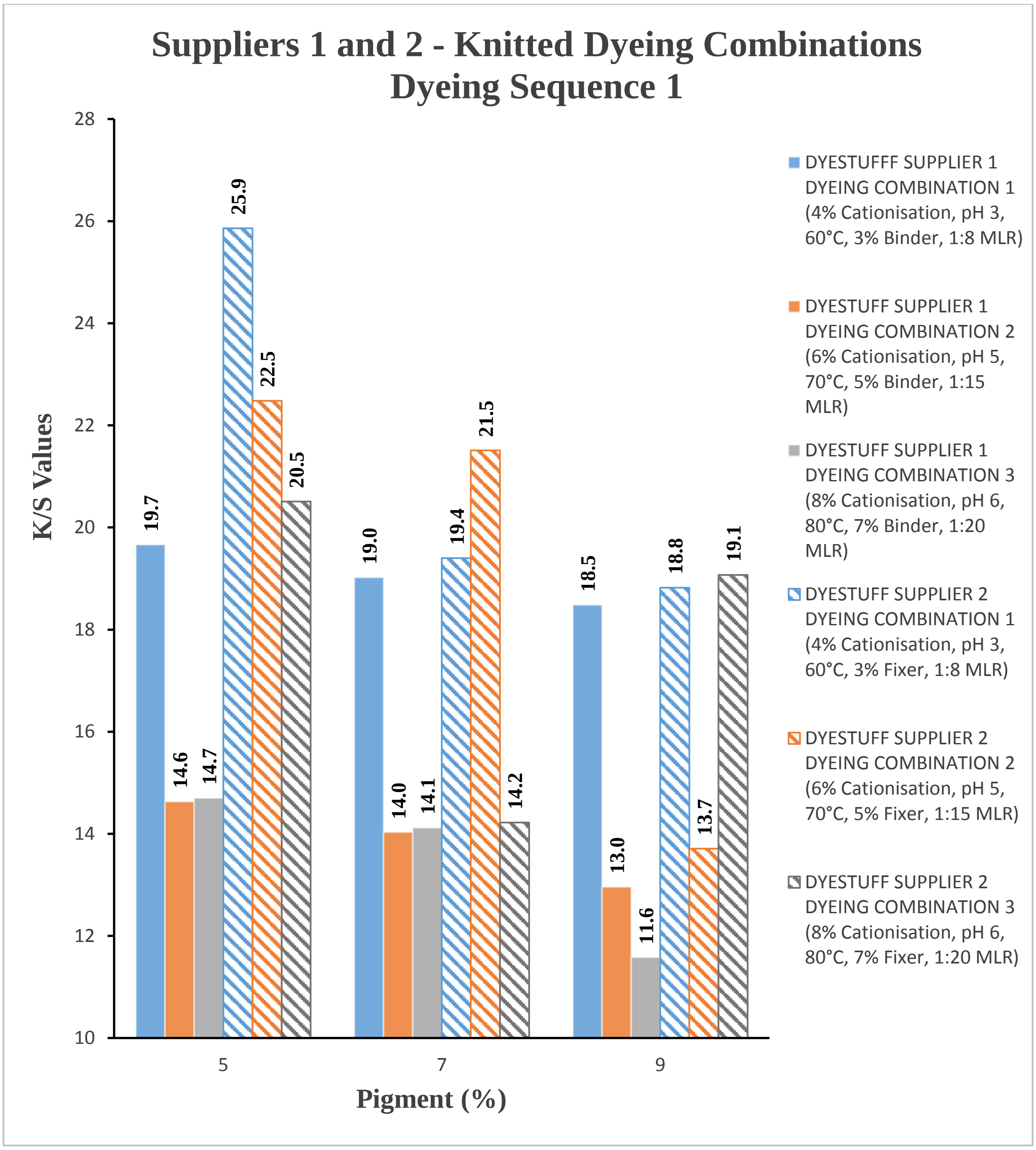


Figure 4.34 Effect of Pigment Concentration (%) on KS for the Dyeing Combinations for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

Table 4.36, indicates that Supplier 1 achieves acceptable pass ratings of 3/4 at 9% pigment for dyeing combination 1, and at all pigment concentrations for dyeing combination 2, as well as at 7 and 9% pigment for dyeing combination 3, however, Supplier 2, only achieves acceptable pass ratings at 7 and 9% pigment for dyeing combination 1. In addition, Figure 4.35 shows the dyeing combinations that have passed on all fastness with a rating of 3/4. Accordingly, both suppliers achieves a pass for the pigment concentration trials, with the K/S for Supplier 2 being much higher than that for Supplier 1.

Table 4.36 Knitted Test Results for Pigment Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - DYESTUFF SUPPLIER 1

Pigment Trials:							KNITTED												Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	19.7	4/5	3/4	4/5	3	3/4	2/3	2/3	2	2/3	19.1	14.9
	4	3	7	60	3	1:8	19.0	4/5	4/5	4/5	4	4/5	2	2/3	3	2/3		
	4	3	9	60	3	1:8	18.5	4/5	4	4/5	4	4/5	3/4	4	4	4		
2	6	5	5	70	5	1:15	14.6	4/5	5	5	5	4/5	4	4	4	4	13.9	
	6	5	7	70	5	1:15	14.0	5	4/5	4/5	4/5	4/5	4	3/4	4	4		
	6	5	9	70	5	1:15	13.0	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
3	8	6	5	80	7	1:20	14.7	4/5	5	5	5	5	4	3	4	3/4	13.5	
	8	6	7	80	7	1:20	14.1	4/5	5	5	5	5	4/5	4	4	4		
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4		

SEQUENCE 1 - DYESTUFF SUPPLIER 2

Pigment Trials:							KNITTED												Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.9	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3	21.4	18.7
	4	3	7	60	3	1:8	19.4	5	5	5	5	5	4/5	4	4	4/5		
	4	3	9	60	3	1:8	18.8	5	5	5	5	5	4/5	4/5	4/5	4		
2	6	5	5	70	5	1:15	22.5	5	5	5	5	4/5	2/3	2/3	2	2/3	19.2	
	6	5	7	70	5	1:15	21.5	5	4/5	5	5	4/5	3/4	3	3	3		
	6	5	9	70	5	1:15	13.7	5	5	5	5	4/5	3/4	4	3/4	3		
3	8	6	5	80	7	1:20	20.5	5	4/5	4/5	4/5	4/5	2	2	2	3	17.9	
	8	6	7	80	7	1:20	14.2	5	4/5	4/5	4/5	5	2/3	2	2/3	2/3		
	8	6	9	80	7	1:20	19.1	5	4/5	4/5	5	5	2/3	2/3	2/3	3		

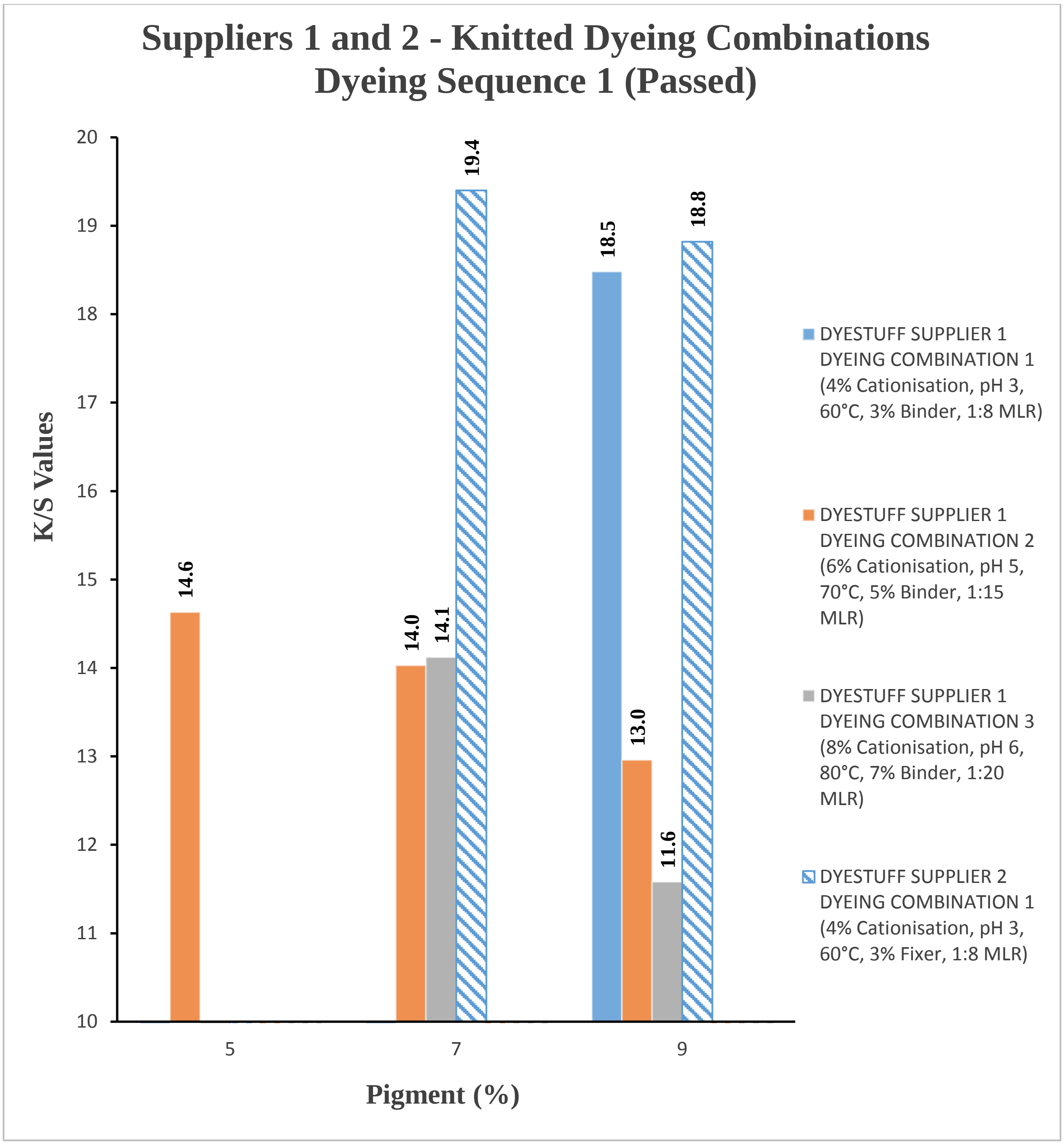


Figure 4.35 Grey Scale Ratings of 3/4 or Higher for Pigment Concentration Trials for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

4.3.3.1.2. Woven Fabric Results

The K/S for both suppliers is represented in Figure 4.36, which shows the K/S, for the woven fabric, for Supplier 2, being higher than that for Supplier 1; with the greatest K/S seen at 5% pigment. Supplier 1, shows a decrease in K/S at each pigment level, as the levels of the remaining parameters are increased, whereas Supplier 2 exhibits the same trend at 5% pigment. Suppliers 1 and 2, show a decrease in K/S for dyeing combinations 1 and 2, as the pigment concentration increases from 5 to 7 to 9%.

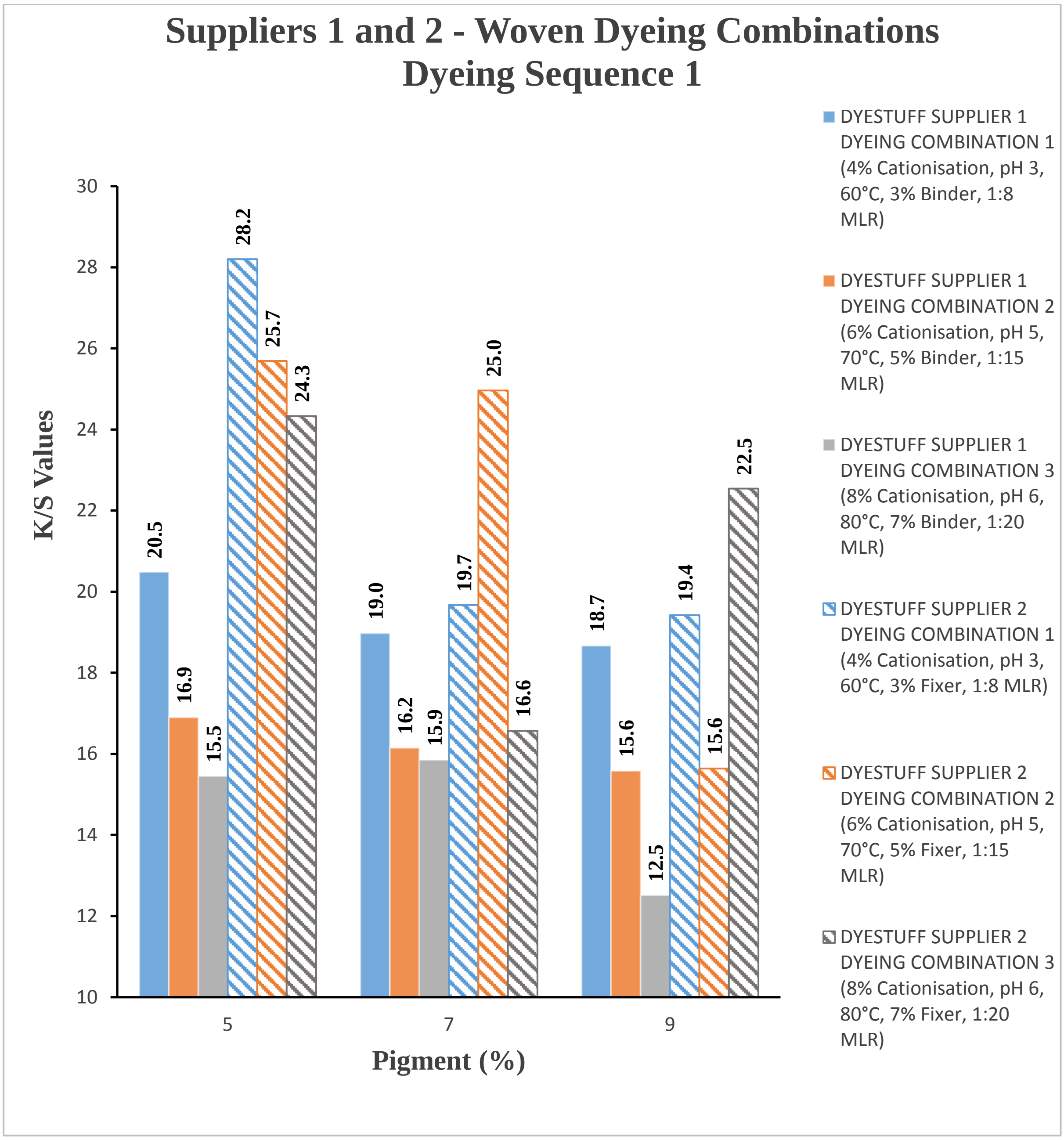


Figure 4.36 Effect of Pigment Concentration (%) on KS for the Dyeing Combinations for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

Table 4.37, shows that Supplier 1 achieves acceptable pass ratings of 3/4 at 5 and 9% pigment for dyeing combination 1, and at all pigment levels for dyeing combinations 2 and 3. Supplier 2, only achieves acceptable pass ratings at 7 and 9% pigment for dyeing combination 1. In addition, Figure 4.37 shows the dyeing combinations that have passed on all fastness criteria, with the K/S for Supplier 1, for dyeing combination 1, being higher than that for Supplier 2.

Table 4.37 Woven Test Results for Pigment Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
Pigment Trials:							WOVEN										Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	20.5	4/5	4/5	4/5	4/5	4/5	4	4/5	3/4	4	19.4	16.3
	4	3	7	60	3	1:8	19.0	4/5	4/5	4	4	4/5	3/4	3/4	3	3		
	4	3	9	60	3	1:8	18.7	4/5	4	4/5	4/5	4/5	4	4/5	4	4		
2	6	5	5	70	5	1:15	16.9	4/5	4/5	4/5	4/5	4/5	4	4	3/4	3/4	16.2	
	6	5	7	70	5	1:15	16.2	5	4/5	4/5	4/5	4/5	4/5	4/5	4	3/4		
	6	5	9	70	5	1:15	15.6	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
3	8	6	5	80	7	1:20	15.5	4/5	5	5	5	5	4	4/5	4	4	14.6	
	8	6	7	80	7	1:20	15.9	4/5	5	5	5	5	4/5	4/5	4/5	4		
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4		
SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
Pigment Trials:							WOVEN										Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	28.2	5	4/5	4/5	5	4/5	3	3	3	2/3	22.4	21.1
	4	3	7	60	3	1:8	19.7	5	5	5	5	5	4/5	4	4	4		
	4	3	9	60	3	1:8	19.4	5	5	5	5	4/5	4/5	4/5	3/4	4		
2	6	5	5	70	5	1:15	25.7	5	5	5	5	4/5	2/3	2/3	2/3	2/3	22.1	
	6	5	7	70	5	1:15	25.0	5	4/5	4/5	5	4/5	3	3	4	4		
	6	5	9	70	5	1:15	15.6	5	5	4/5	5	5	2/3	2/3	3/4	3		
3	8	6	5	80	7	1:20	24.3	5	5	5	5	4/5	3	3	4/5	3	21.1	
	8	6	7	80	7	1:20	16.6	5	5	4/5	5	4/5	3/4	3	3	2/3		
	8	6	9	80	7	1:20	22.5	5	5	5	5	4/5	3	4	3/4	3		

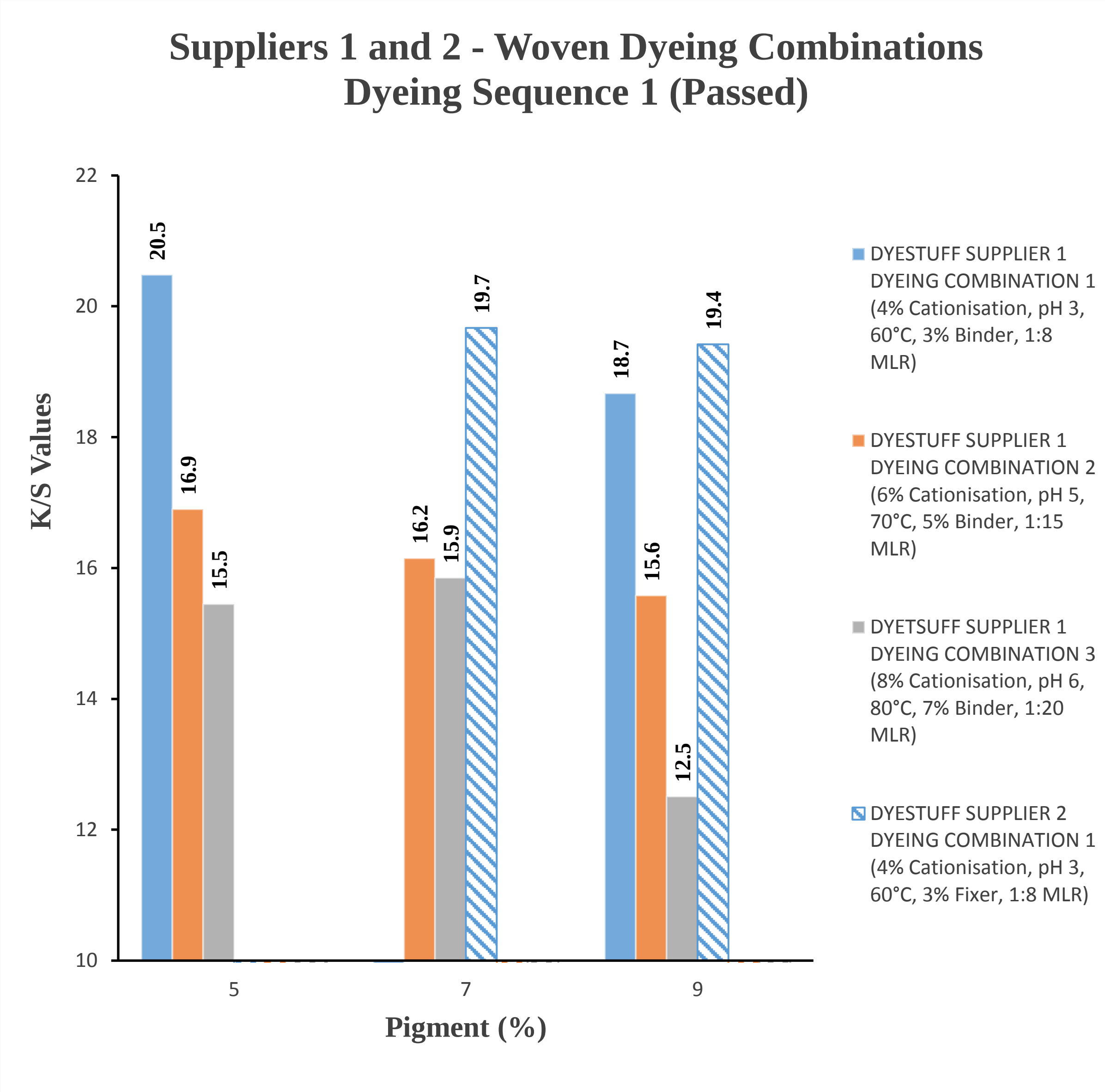


Figure 4.37 Grey Scale Ratings of 3/4 or Higher for Pigment Concentration Trials for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

4.3.3.2. DISCUSSION

Supplier 2 obtained a higher K/S for both the knitted and woven fabrics, than that for Supplier 1, with acceptable pass ratings of 3/4, as indicated in Figures 4.35 and 4.37, which show that Supplier 1 obtained pass ratings at all pigment concentrations for both fabrics, whereas Supplier 2 obtained pass ratings at 7 and 9% pigment for both fabrics. In addition, six dyeing combinations for the knitted, and 5 for the woven, achieved pass ratings of 4 or higher for all fastness criteria. Tables 4.38 and 4.39 represents the knitted and woven dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for the knitted being K/S of 19.4 and the woven 19.7, both at 7% pigment for dyeing combination 1, for Supplier 2.

Table 4.38 Ideal Dyeing Combinations for Knitted Fabric for Pigment Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - SUPPLIER 1																
Pigment Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
2	6	5	5	70	5	1:15	14.6	4/5	5	5	5	4/5	4	4	4	4
	6	5	9	70	5	1:15	13.0	4/5	4/5	4/5	4/5	4/5	4	4	4	4
3	8	6	7	80	7	1:20	14.1	4/5	5	5	5	5	4/5	4	4	4
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4
SEQUENCE 1 - SUPPLIER 2																
Pigment Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	7	60	3	1:8	19.4	5	5	5	5	5	4/5	4	4	4/5
	4	3	9	60	3	1:8	18.8	5	5	5	5	5	4/5	4/5	4/5	4

Table 4.39 Ideal Dyeing Combinations for Woven Fabric for Pigment Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - SUPPLIER 1																
Pigment Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
2	6	5	9	70	5	1:15	15.6	4/5	4/5	4/5	4/5	4/5	4	4	4	4
3	8	6	5	80	7	1:20	15.5	4/5	5	5	5	5	4	4/5	4	4
	8	6	7	80	7	1:20	15.9	4/5	5	5	5	5	4/5	4/5	4/5	4
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4
SEQUENCE 1 - SUPPLIER 2																
Pigment Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	7	60	3	1:8	19.7	5	5	5	5	5	4/5	4	4	4

4.3.3.3. SUPPLIERS 1 AND 2 (DYEING SEQUENCE 2)

4.3.3.3.1. Knitted Fabric Results

The K/S for both suppliers is represented in Figure 4.38, with the highest K/S seen at 9% pigment for Supplier 2. All dyeing combinations for Suppliers 1 and 2, show a decrease in K/S at each pigment level, as the level of the remaining parameters are increased. Furthermore, dyeing combinations 2 and 3 for Supplier 1 show a decrease in K/S as the pigment is increased from 5 to 7 to 9%, whereas Supplier 2 shows an increase in K/S as the pigment is increased from 5 to 7 to 9%, for dyeing combination 1.

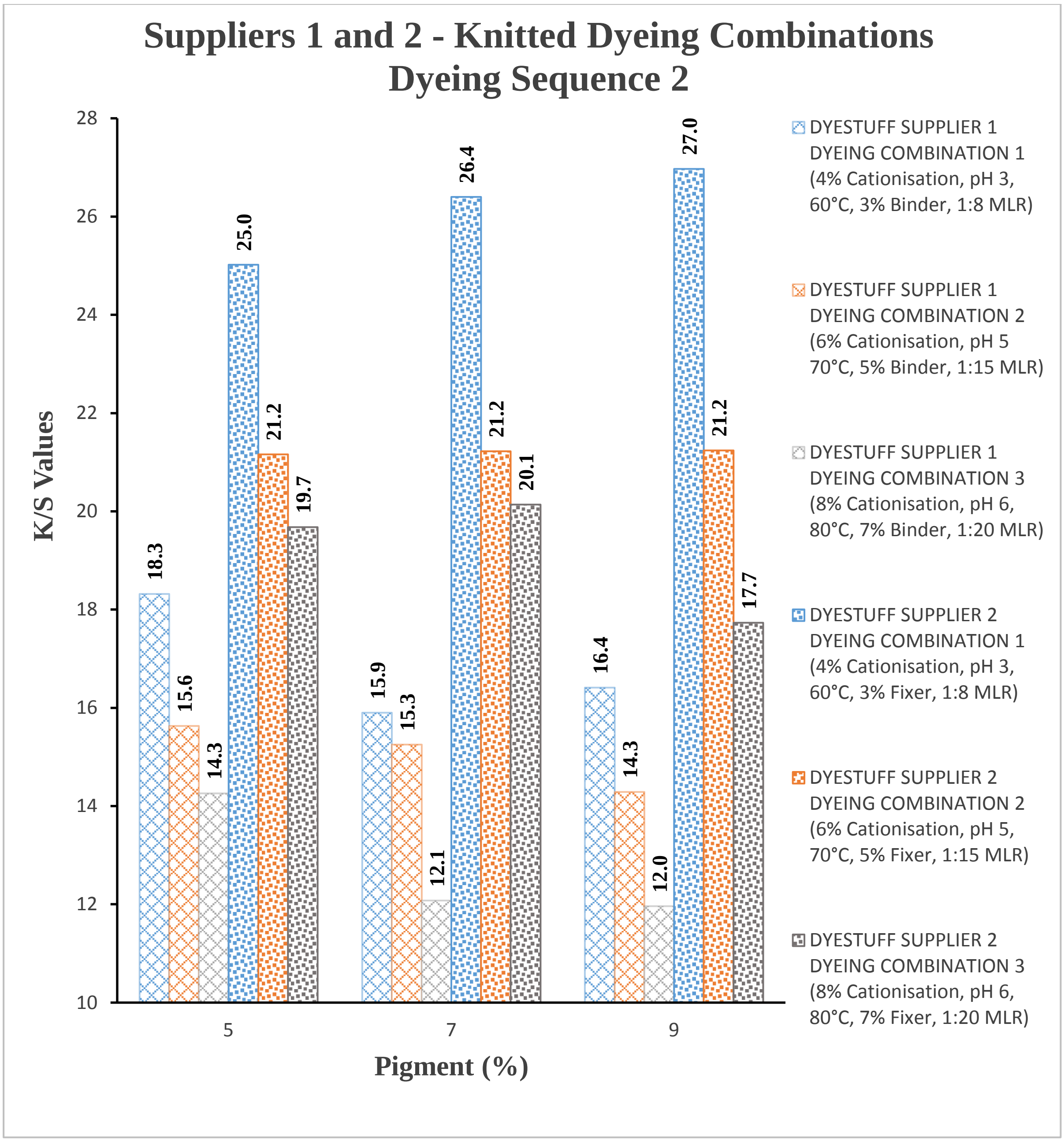


Figure 4.38 Effect of Pigment Concentration (%) on K/S for the Dyeing Combinations for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

Table 4.40, shows that Supplier 1 does not achieve acceptable pass ratings of 3/4 at all dyeing combinations for pigment, whereas Supplier 2 does so at all pigment concentrations for dyeing combination 1. In addition, Figure 4.39 shows the dyeing combinations that have passed on all fastness criteria, with the K/S for Supplier 2 relatively high.

Table 4.40 Knitted Test Results for Pigment Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Pigment Trials:							KNITTED										Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	18.3	5	4	4	4	4	2/3	2/3	2/3	3	16.9	14.5
	4	3	7	60	3	1:8	15.9	4/5	4/5	4/5	4/5	4/5	2/3	2/3	2/3	3		
	4	3	9	60	3	1:8	16.4	5	4/5	4/5	4/5	4/5	3	3/4	3	3		
2	6	5	5	70	5	1:15	15.6	4/5	4	4/5	4/5	4/5	2/3	2/3	3	3	15.1	
	6	5	7	70	5	1:15	15.3	5	4/5	4/5	4/5	4/5	3/4	3	3	3		
	6	5	9	70	5	1:15	14.3	5	4/5	4/5	4/5	4/5	3	3/4	3	3		
3	8	6	5	80	7	1:20	14.3	4/5	4	4/5	4	4/5	2/3	2	2/3	2	12.8	
	8	6	7	80	7	1:20	12.1	5	4/5	4/5	4/5	4	2/3	2/3	2	2		
	8	6	9	80	7	1:20	12.0	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3		

SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Pigment Trials:							KNITTED										Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.0	5	4/5	5	5	5	3/4	4	4	4	26.1	21.8
	4	3	7	60	3	1:8	26.4	5	5	5	5	5	4/5	4	4/5	4		
	4	3	9	60	3	1:8	27.0	5	5	5	5	5	4/5	4/5	4/5	4/5		
2	6	5	5	70	5	1:15	21.2	5	4/5	5	5	5	2/3	2/3	2	2/3	21.2	
	6	5	7	70	5	1:15	21.2	5	4	4	4/5	4/5	2/3	2/3	2	3		
	6	5	9	70	5	1:15	21.2	5	5	5	5	5	3/4	3	3/4	3/4		
3	8	6	5	80	7	1:20	19.7	4/5	5	4/5	4/5	5	3/4	3	3/4	3	19.2	
	8	6	7	80	7	1:20	20.1	5	4/5	4/5	4/5	4/5	3	3	3	3		
	8	6	9	80	7	1:20	17.7	5	4/5	4/5	5	4/5	2/3	2	2	2/3		

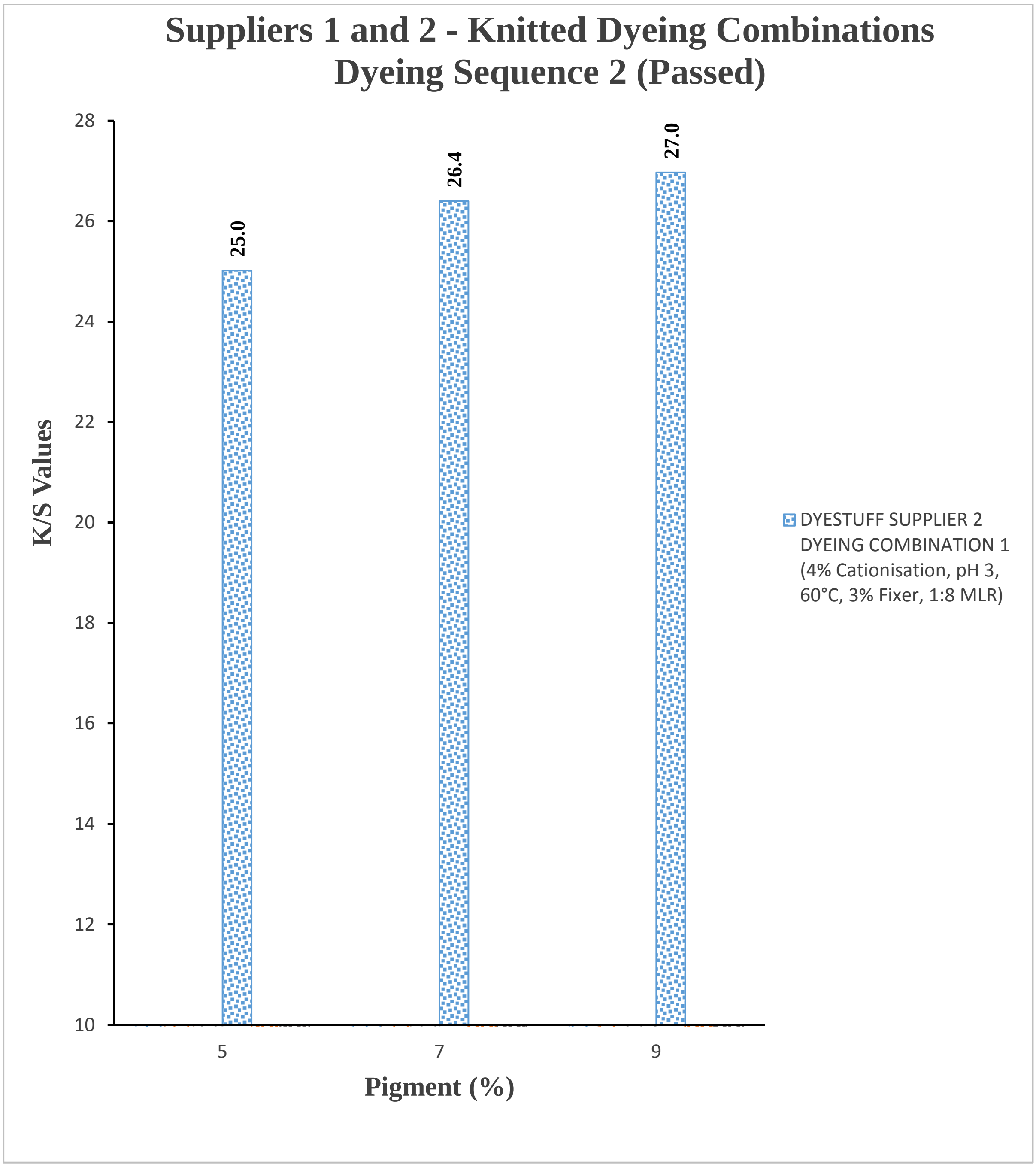


Figure 4.39 Grey Scale Ratings of 3/4 or Higher for Pigment Concentration Trials for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

4.3.3.3.2. Woven Fabric Results

The K/S for Suppliers 1 and 2 is represented in Figure 4.40, with the highest K/S seen at 7% pigment for dyeing sequence 2. All dyeing combinations for Suppliers 1 and 2, show a decrease in K/S at each pH level, as the level of the remaining parameters are increased. A decrease in K/S is also visible for dyeing combination 3 for Supplier 1, and for dyeing combination 2 for Supplier 2, as the pigment is increased from 5 to 7 to 9%.

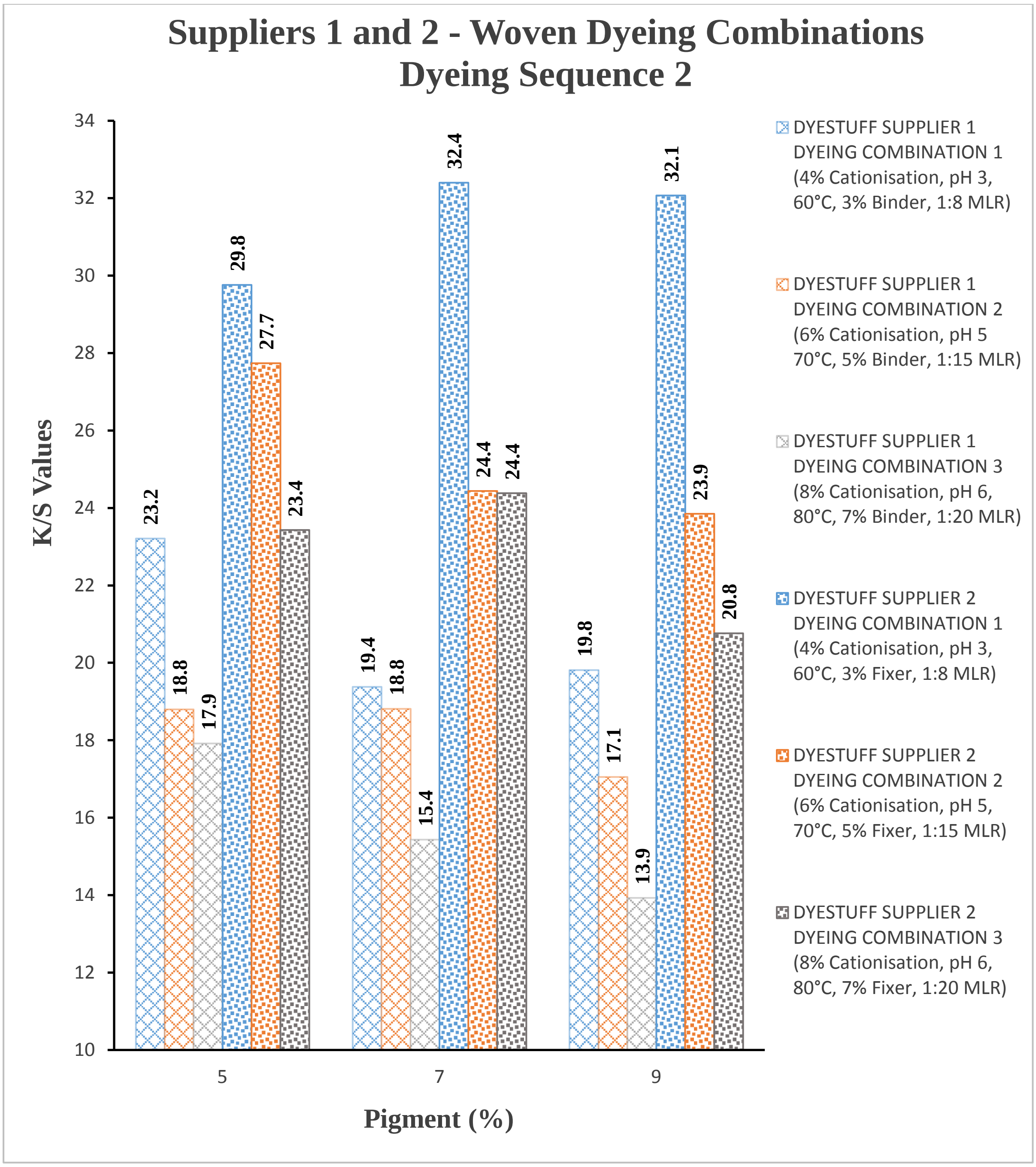


Figure 4.40 Effect of Pigment Concentration (%) on KS for the Dyeing Combinations for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

Table 4.41, shows that Supplier 1 achieves an acceptable pass rating of 3/4 at 5% pigment for dyeing combination 1; while Supplier 2 achieves the same at all pigment concentrations for dyeing combination 1, and at 5% pigment for dyeing combination 3. In addition, Figure 4.41 shows the dyeing combinations that have passed on all fastness criteria with a rating of 3/4, with the corresponding K/S for Supplier 2 being relatively higher than that for Supplier 1.

Table 4.41 Woven Test Results for Pigment Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Pigment Trials:							WOVEN										Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub Face	Warp Dry Rub Back	Weft Dry Rub Face	Weft Dry Rub Back	Warp Wet Rub Face	Warp Wet Rub Back	Weft Wet Rub Face	Weft Wet Rub Back		
1	4	3	5	60	3	1:8	23.2	5	4/5	4/5	4/5	4/5	3	3	3	3	20.8	17.6
	4	3	7	60	3	1:8	19.4	5	4/5	4/5	4/5	4/5	3/4	3	3/4	3		
	4	3	9	60	3	1:8	19.8	5	4/5	4/5	4/5	4/5	4	3/4	3	3		
2	6	5	5	70	5	1:15	18.8	5	4/5	4/5	4/5	4/5	4	3/4	3/4	3	18.2	
	6	5	7	70	5	1:15	18.8	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3/4		
	6	5	9	70	5	1:15	17.1	5	4/5	4/5	4/5	5	3	4	3	3		
3	8	6	5	80	7	1:20	17.9	5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3/4	15.8	
	8	6	7	80	7	1:20	15.4	5	4/5	4/5	4/5	4/5	3/4	3	3	2/3		
	8	6	9	80	7	1:20	13.9	4/5	4/5	4/5	4/5	4/5	3/4	3	3	3		

SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Pigment Trials:							WOVEN										Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub Face	Warp Dry Rub Back	Weft Dry Rub Face	Weft Dry Rub Back	Warp Wet Rub Face	Warp Wet Rub Back	Weft Wet Rub Face	Weft Wet Rub Back		
1	4	3	5	60	3	1:8	29.8	5	5	5	5	5	4	4	3/4	3/4	31.4	26.1
	4	3	7	60	3	1:8	32.4	5	5	5	5	5	4	4/5	3/4	3/4		
	4	3	9	60	3	1:8	32.1	5	5	5	5	5	4/5	4/5	4	4		
2	6	5	5	70	5	1:15	27.7	5	5	5	4/5	4/5	3	2/3	3	4/5	25.3	
	6	5	7	70	5	1:15	24.4	5	5	5	5	5	3/4	3	3	4		
	6	5	9	70	5	1:15	23.9	5	5	5	5	5	3/4	3/4	3	3		
3	8	6	5	80	7	1:20	23.4	5	5	5	5	5	4	3/4	3/4	4	22.9	
	8	6	7	80	7	1:20	24.4	5	5	5	5	5	4/5	4/5	3	3/4		
	8	6	9	80	7	1:20	20.8	5	5	5	5	5	3	3	3	2		

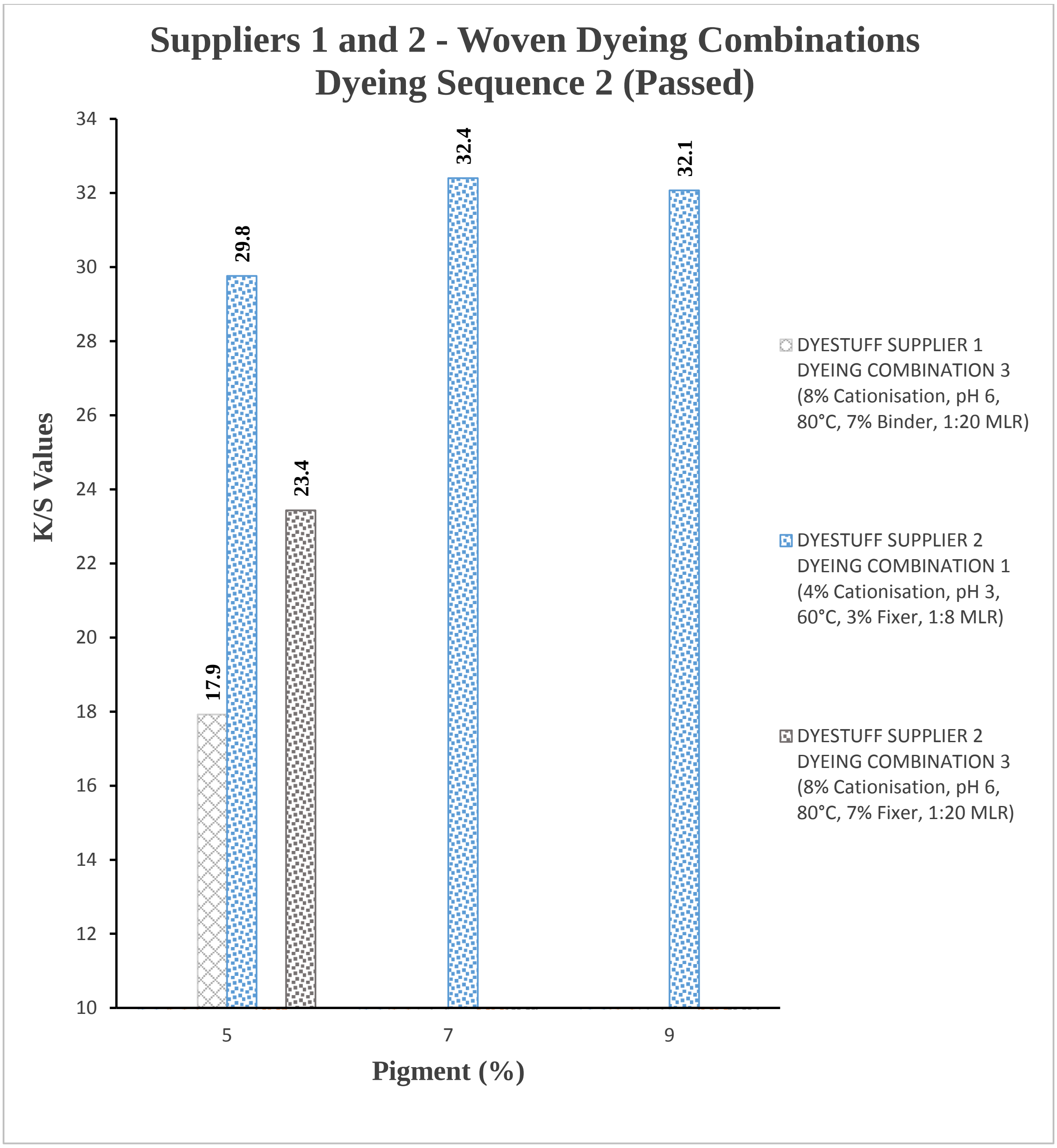


Figure 4.41 Grey Scale Ratings of 3/4 or Higher for Pigment Concentration Trials for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

4.3.3.4. <u>DISCUSSION</u>

Supplier 2 obtained a higher K/S for both the knitted and woven fabrics, than that for Supplier 1, with acceptable pass ratings of 3/4, as indicated in Figures 4.39 and 4.41, which showed that only Supplier 2 for the knitted, obtained pass ratings at all pigment concentrations for dyeing combination 1, while the woven fabric showed that Supplier 1 only obtained a pass rating at 5% pigment for dyeing combination 3. In addition, only two dyeing combinations for the knitted fabric, for Supplier 2, achieved pass ratings of 4 or higher for all fastness, while the woven fabric which did not. Table 4.42, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for knitted being K/S of 27.0 at 9% pigment for dyeing combination 2, sequence 2, Supplier 2.

Table 4.42 Ideal Dyeing Combinations for Knitted Fabric for Pigment Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - SUPPLIER 2																		
Pigment Trials:							KNITTED											
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
2	4	3	7	60	3	1:8	26.4	5	5	5	5	5	4/5	4	4/5	4		
	4	3	9	60	3	1:8	27.0	5	5	5	5	5	4/5	4/5	4/5	4/5		

4.3.3.5. SUPPLIER 1 (DYEING SEQUENCE 1 AND 2)

4.3.3.5.1. Knitted Fabric Results

The K/S for Supplier 1, dyeing sequence 1 and 2, is represented in Figure 4.42, with the highest K/S seen at 5% pigment for dyeing sequence 1. All dyeing combinations for sequence 2, show a decrease in K/S at each pigment level, as the level of the remaining parameters are increased. Sequence 1, for all dyeing combinations, show a decrease in K/S as the pigment concentration is increased from 5 to 7 to 9%. Sequence 2, however, shows the same trend for dyeing combinations 2 and 3 as the pigment concentration is increased from 5 to 7 to 9%.

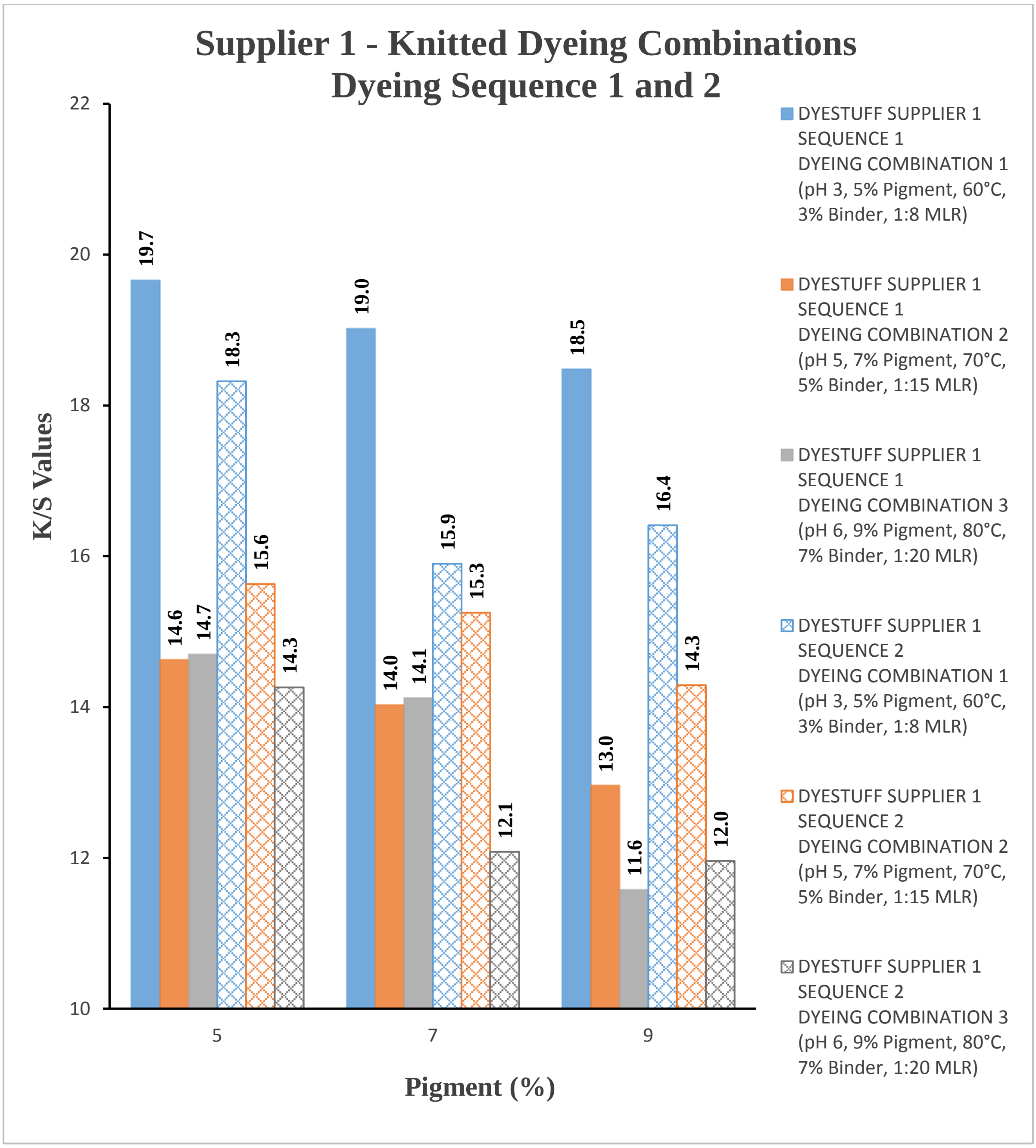


Figure 4.42 Effect of Pigment (%) on K/S for the Dyeing Combinations for Knitted Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

Table 4.43, shows that sequence 1 achieves an acceptable pass rating of 3/4 at 9% pigment for dyeing combination 1, and at all pigment levels for dyeing combination 2, as well as at 7 and 9% pigment for dyeing combination 3; whereas sequence 2 does not achieve any pass ratings for all pigment levels across any dyeing combinations. In addition, Figure 4.43 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, only dyeing sequence 1 achieves a pass at all pigment concentrations, with the K/S values being relatively higher than that for sequence 2.

Table 4.43 Knitted Test Results for Pigment Concentration Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
Pigment Trials:							KNITTED										Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	19.7	4/5	3/4	4/5	3	3/4	2/3	2/3	2	2/3	19.1	14.9
	4	3	7	60	3	1:8	19.0	4/5	4/5	4/5	4	4/5	2	2/3	3	2/3		
	4	3	9	60	3	1:8	18.5	4/5	4	4/5	4	4/5	3/4	4	4	4		
2	6	5	5	70	5	1:15	14.6	4/5	5	5	5	4/5	4	4	4	4	13.9	
	6	5	7	70	5	1:15	14.0	5	4/5	4/5	4/5	4/5	4	3/4	4	4		
	6	5	9	70	5	1:15	13.0	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
3	8	6	5	80	7	1:20	14.7	4/5	5	5	5	5	4	3	4	3/4	13.5	
	8	6	7	80	7	1:20	14.1	4/5	5	5	5	5	4/5	4	4	4		
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4		

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Pigment Trials:							KNITTED										Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	18.3	5	4	4	4	4	2/3	2/3	2/3	3	16.9	14.5
	4	3	7	60	3	1:8	15.9	4/5	4/5	4/5	4/5	4/5	2/3	2/3	2/3	3		
	4	3	9	60	3	1:8	16.4	5	4/5	4/5	4/5	4/5	3	3/4	3	3		
2	6	5	5	70	5	1:15	15.6	4/5	4	4/5	4/5	4/5	2/3	2/3	3	3	15.1	
	6	5	7	70	5	1:15	15.3	5	4/5	4/5	4/5	4/5	3/4	3	3	3		
	6	5	9	70	5	1:15	14.3	5	4/5	4/5	4/5	4/5	3	3/4	3	3		
3	8	6	5	80	7	1:20	14.3	4/5	4	4/5	4	4/5	2/3	2	2/3	2	12.8	
	8	6	7	80	7	1:20	12.1	5	4/5	4/5	4/5	4	2/3	2/3	2	2		
	8	6	9	80	7	1:20	12.0	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3		

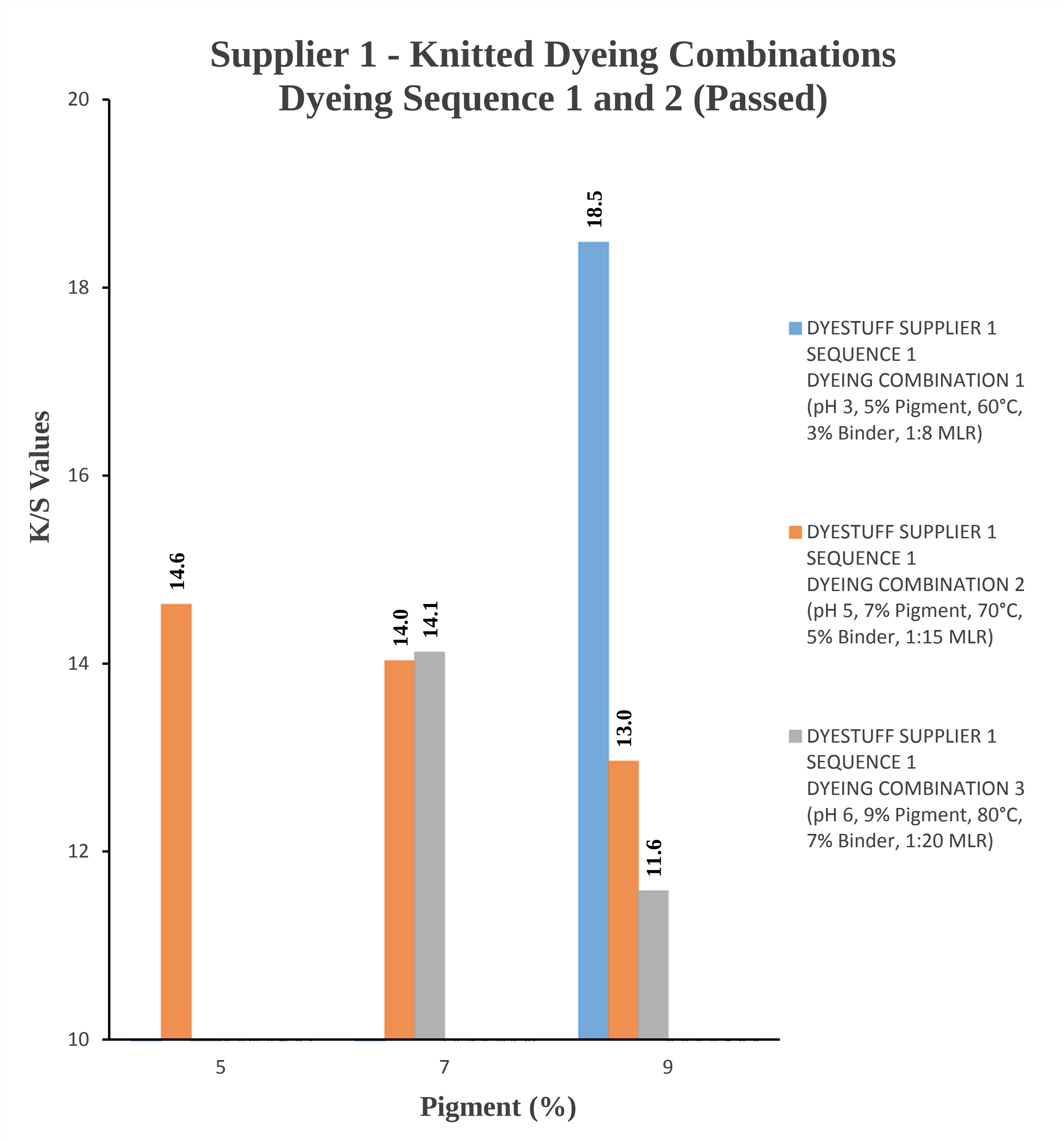


Figure 4.43 Grey Scale Ratings of 3/4 or Higher for Pigment Concentration Trials for Knitted Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

4.3.3.5.2. Woven Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.44, with the highest K/S seen at 5% pigment for dyeing sequence 2. All dyeing combinations for sequence 1 and 2, show a decrease in K/S at all pigment levels, as the level of the remaining parameters are increased. Sequence 1, for dyeing combinations 1 and 2 show a decrease in K/S as the pigment concentration is increased from 5 to 7 to 9%, with the same observed for sequence 2 for dyeing combinations 2 and 3.

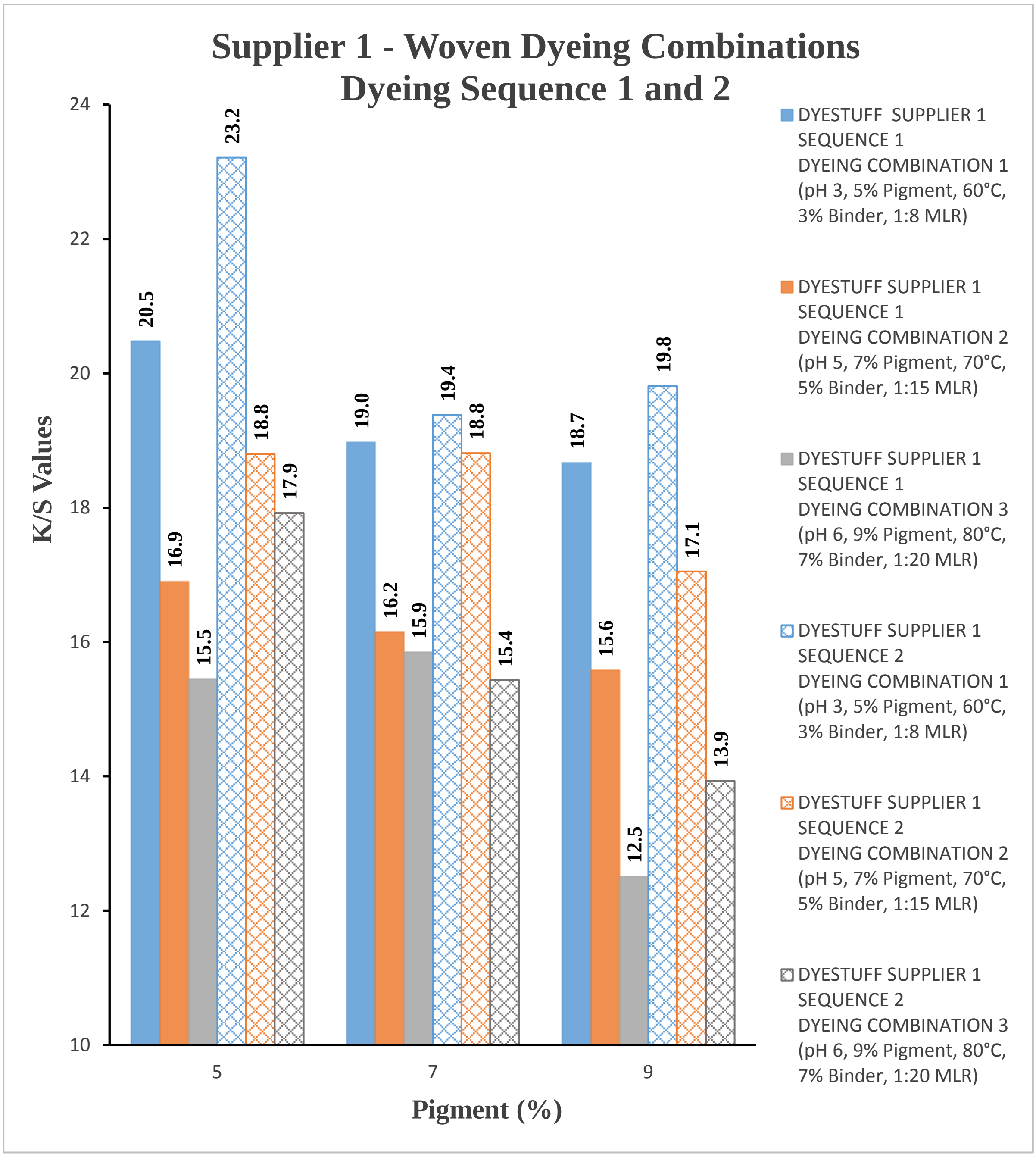


Figure 4.44 Effect of Pigment (%) on KS for the Dyeing Combinations for Woven Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

Table 4.44, shows that sequence 1 achieves an acceptable pass rating of 3/4 at 5 and 9% pigment for dyeing combination 1, as well as at all pigment levels for dyeing combinations 2 and 3; whereas sequence 2, only achieves a pass rating at 5% pigment for dyeing combination 3. In addition, Figure 4.45 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Although sequence 1 achieves a pass at all pigment concentrations, the K/S is relatively lower than that for sequence 2.

Table 4.44 Woven Test Results for Pigment Concentration Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
Pigment Trials:							WOVEN										Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	20.5	4/5	4/5	4/5	4/5	4/5	4	4/5	3/4	4	19.4	16.3
	4	3	7	60	3	1:8	19.0	4/5	4/5	4	4	4/5	3/4	3/4	3	3		
	4	3	9	60	3	1:8	18.7	4/5	4	4/5	4/5	4/5	4	4/5	4	4		
2	6	5	5	70	5	1:15	16.9	4/5	4/5	4/5	4/5	4/5	4	4	3/4	3/4	16.2	
	6	5	7	70	5	1:15	16.2	5	4/5	4/5	4/5	4/5	4/5	4/5	4	3/4		
	6	5	9	70	5	1:15	15.6	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
3	8	6	5	80	7	1:20	15.5	4/5	5	5	5	5	4	4/5	4	4	14.6	
	8	6	7	80	7	1:20	15.9	4/5	5	5	5	5	4/5	4/5	4/5	4		
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4		

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Pigment Trials:							WOVEN										Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	23.2	5	4/5	4/5	4/5	4/5	3	3	3	3	20.8	17.6
	4	3	7	60	3	1:8	19.4	5	4/5	4/5	4/5	4/5	3/4	3	3/4	3		
	4	3	9	60	3	1:8	19.8	5	4/5	4/5	4/5	4/5	4	3/4	3	3		
2	6	5	5	70	5	1:15	18.8	5	4/5	4/5	4/5	4/5	4	3/4	3/4	3	18.2	
	6	5	7	70	5	1:15	18.8	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3/4		
	6	5	9	70	5	1:15	17.1	5	4/5	4/5	4/5	5	3	4	3	3		
3	8	6	5	80	7	1:20	17.9	5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3/4	15.8	
	8	6	7	80	7	1:20	15.4	5	4/5	4/5	4/5	4/5	3/4	3	3	2/3		
	8	6	9	80	7	1:20	13.9	4/5	4/5	4/5	4/5	4/5	3/4	3	3	3		

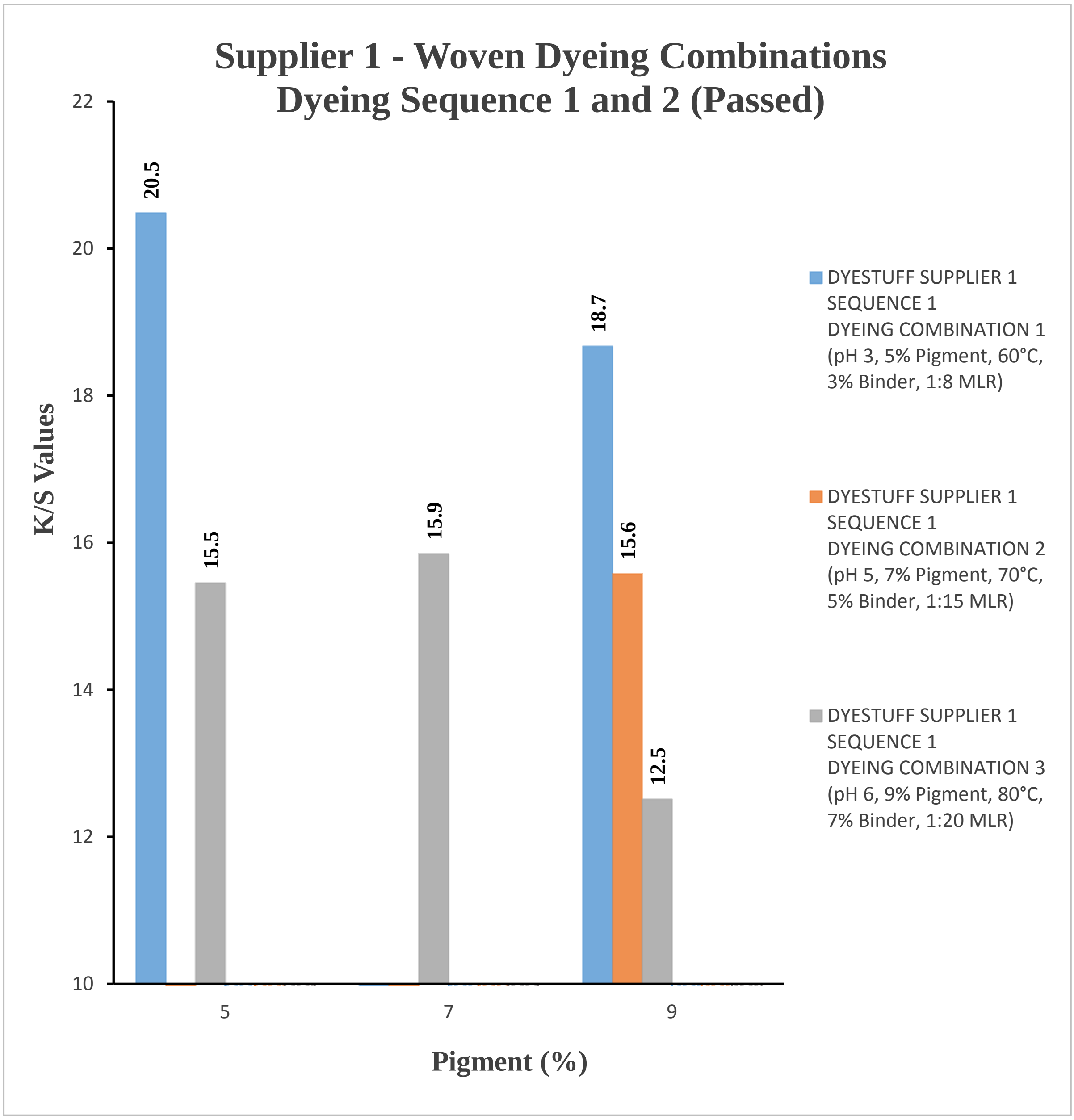


Figure 4.45 Grey Scale Ratings of 3/4 or Higher for Pigment Concentration Trials for Woven Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

4.3.3.6. DISCUSSION

Acceptable pass ratings of 3/4, as indicated in Figures 4.43 and 4.45, showed that only sequence 1 obtained pass ratings at all pigment levels for both knitted and woven fabrics. In addition, 4 dyeing combinations for the knitted, and 5 for the woven, achieved pass ratings of 4 or higher for all fastness, for sequence 1. Tables 4.45 and 4.46, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for knitted being K/S of 14.6 at 5% pigment for dyeing combination 2, and woven being K/S of 18.7 at 9% pigment for dyeing combination 1, both for sequence 1, Supplier 1.

Table 4.45 Ideal Dyeing Combinations for Knitted Fabric for Pigment Concentration Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 1																
Pigment Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
2	6	5	5	70	5	1:15	14.6	4/5	5	5	5	4/5	4	4	4	4
	6	5	9	70	5	1:15	13.0	4/5	4/5	4/5	4/5	4/5	4	4	4	4
3	8	6	7	80	7	1:20	14.1	4/5	5	5	5	5	4/5	4	4	4
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4

Table 4.46 Ideal Dyeing Combinations for Woven Fabric for Pigment Concentration Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 1																
Pigment Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	9	60	3	1:8	18.7	4/5	4	4/5	4/5	4/5	4	4/5	4	4
2	6	5	9	70	5	1:15	15.6	4/5	4/5	4/5	4/5	4/5	4	4	4	4
3	8	6	5	80	7	1:20	15.5	4/5	5	5	5	5	4	4/5	4	4
	8	6	7	80	7	1:20	15.9	4/5	5	5	5	5	4/5	4/5	4/5	4
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4

4.3.3.7. SUPPLIER 2 (DYEING SEQUENCE 1 AND 2)

4.3.3.7.1. Knitted Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.46, with the highest K/S seen at 9% pigment for dyeing sequence 2. All dyeing combinations for sequence 2, show a decrease in K/S at each pigment level, as the levels of the remaining parameters are increased. The only trend visible is a decrease in K/S for dyeing combination 1 and 2, sequence 1, as the pigment concentration is increased from 5 to 7 to 9%, contrary to dyeing combination 1, sequence 2, which shows an increase in K/S as the pigment concentration is increased from 5 to 7 to 9%.

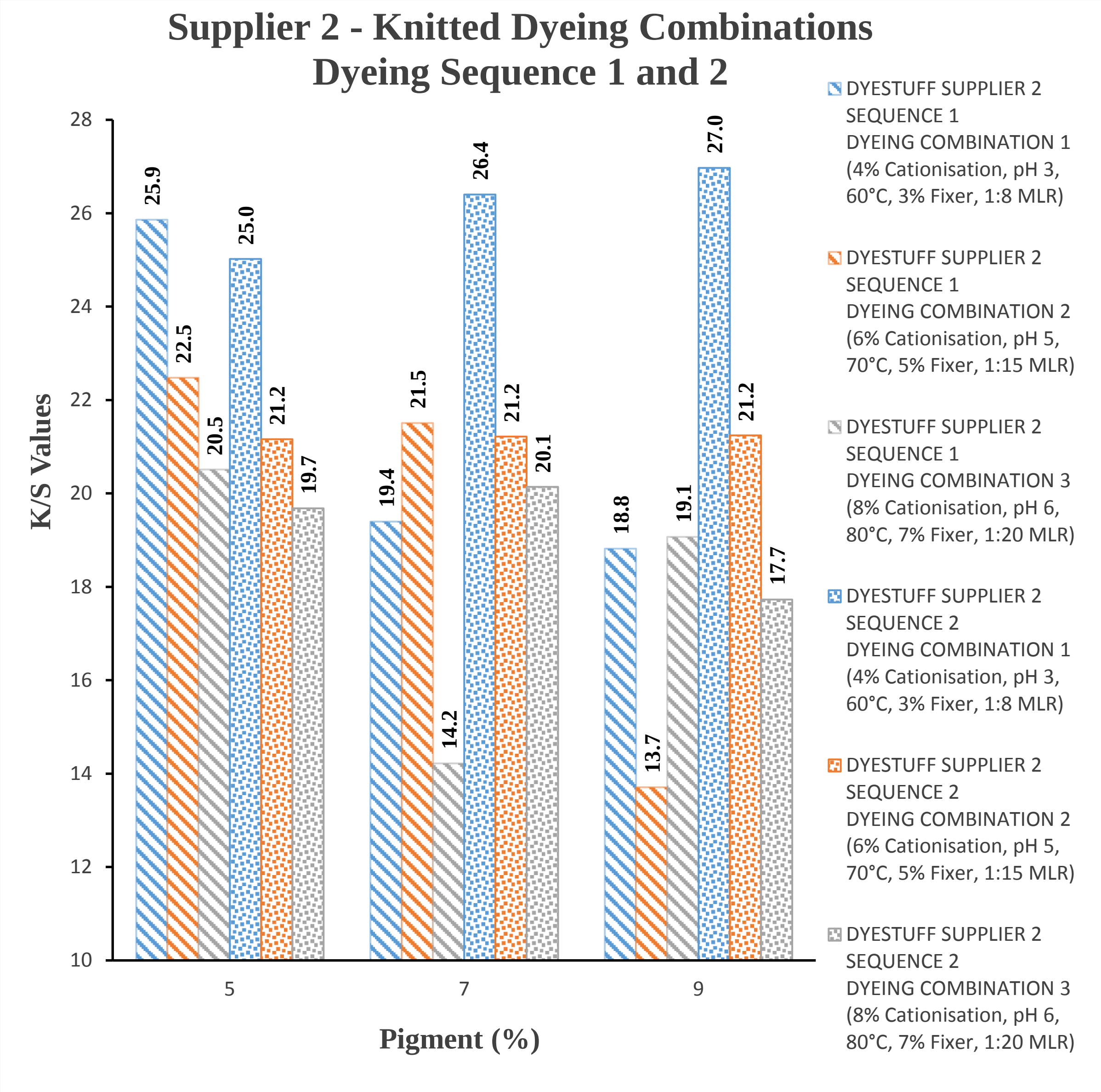


Figure 4.46 Effect of Pigment (%) on K/S for the Dyeing Combinations for Knitted Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

Table 4.47, shows that sequence 1 achieves an acceptable pass rating of 3/4 at 7 and 9% pigment for dyeing combination 1, whereas sequence 2, achieves the same at all pigment concentrations for dyeing combination 1. In addition, Figure 4.47 shows the dyeing combinations that have passed on all fastness with a rating of 3/4. Accordingly, only sequence 2 achieves a pass at all pigment levels, with K/S values higher than that for sequence 1.

Table 4.47 Knitted Test Results for Pigment Concentration Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
Pigment Trials:							KNITTED										Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.9	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3	21.4	18.7
	4	3	7	60	3	1:8	19.4	5	5	5	5	5	4/5	4	4	4/5		
	4	3	9	60	3	1:8	18.8	5	5	5	5	5	4/5	4/5	4/5	4		
2	6	5	5	70	5	1:15	22.5	5	5	5	5	4/5	2/3	2/3	2	2/3	19.2	
	6	5	7	70	5	1:15	21.5	5	4/5	5	5	4/5	3/4	3	3	3		
	6	5	9	70	5	1:15	13.7	5	5	5	5	4/5	3/4	4	3/4	3		
3	8	6	5	80	7	1:20	20.5	5	4/5	4/5	4/5	4/5	2	2	2	3	17.9	
	8	6	7	80	7	1:20	14.2	5	4/5	4/5	4/5	5	2/3	2	2/3	2/3		
	8	6	9	80	7	1:20	19.1	5	4/5	4/5	5	5	2/3	2/3	2/3	3		

SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Pigment Trials:							KNITTED										Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.0	5	4/5	5	5	5	3/4	4	4	4	26.1	21.8
	4	3	7	60	3	1:8	26.4	5	5	5	5	5	4/5	4	4/5	4		
	4	3	9	60	3	1:8	27.0	5	5	5	5	5	4/5	4/5	4/5	4/5		
2	6	5	5	70	5	1:15	21.2	5	4/5	5	5	5	2/3	2/3	2	2/3	21.2	
	6	5	7	70	5	1:15	21.2	5	4	4	4/5	4/5	2/3	2/3	2	3		
	6	5	9	70	5	1:15	21.2	5	5	5	5	5	3/4	3	3/4	3/4		
3	8	6	5	80	7	1:20	19.7	4/5	5	4/5	4/5	5	3/4	3	3/4	3	19.2	
	8	6	7	80	7	1:20	20.1	5	4/5	4/5	4/5	4/5	3	3	3	3		
	8	6	9	80	7	1:20	17.7	5	4/5	4/5	5	4/5	2/3	2	2	2/3		

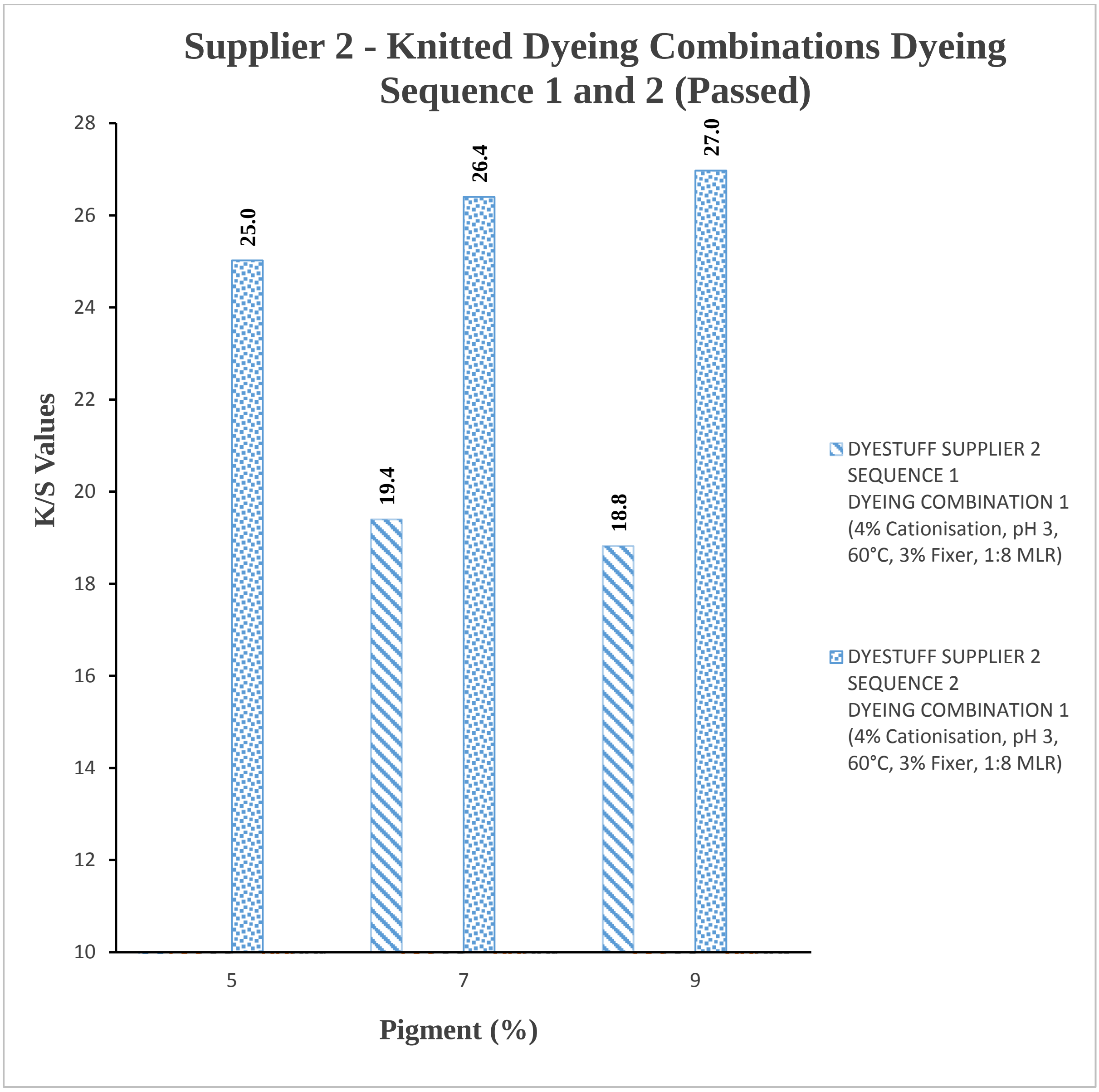


Figure 4.47 Grey Scale Ratings of 3/4 or Higher for Pigment Concentration Trials for Knitted Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

4.3.3.7.2. Woven Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.48, with the highest K/S seen at 7% pigment for dyeing sequence 2. All dyeing combinations for sequence 1, show a decrease in K/S at 5% pigment, as the levels of the remaining parameters are increased, with the same achieved for sequence 2 at all levels of pigment. The only trend visible is a decrease in K/S for dyeing combination 1 and 2, sequence 1, as well as dyeing combination 2, sequence 2, as the pigment concentration is increased from 5 to 7 to 9%.

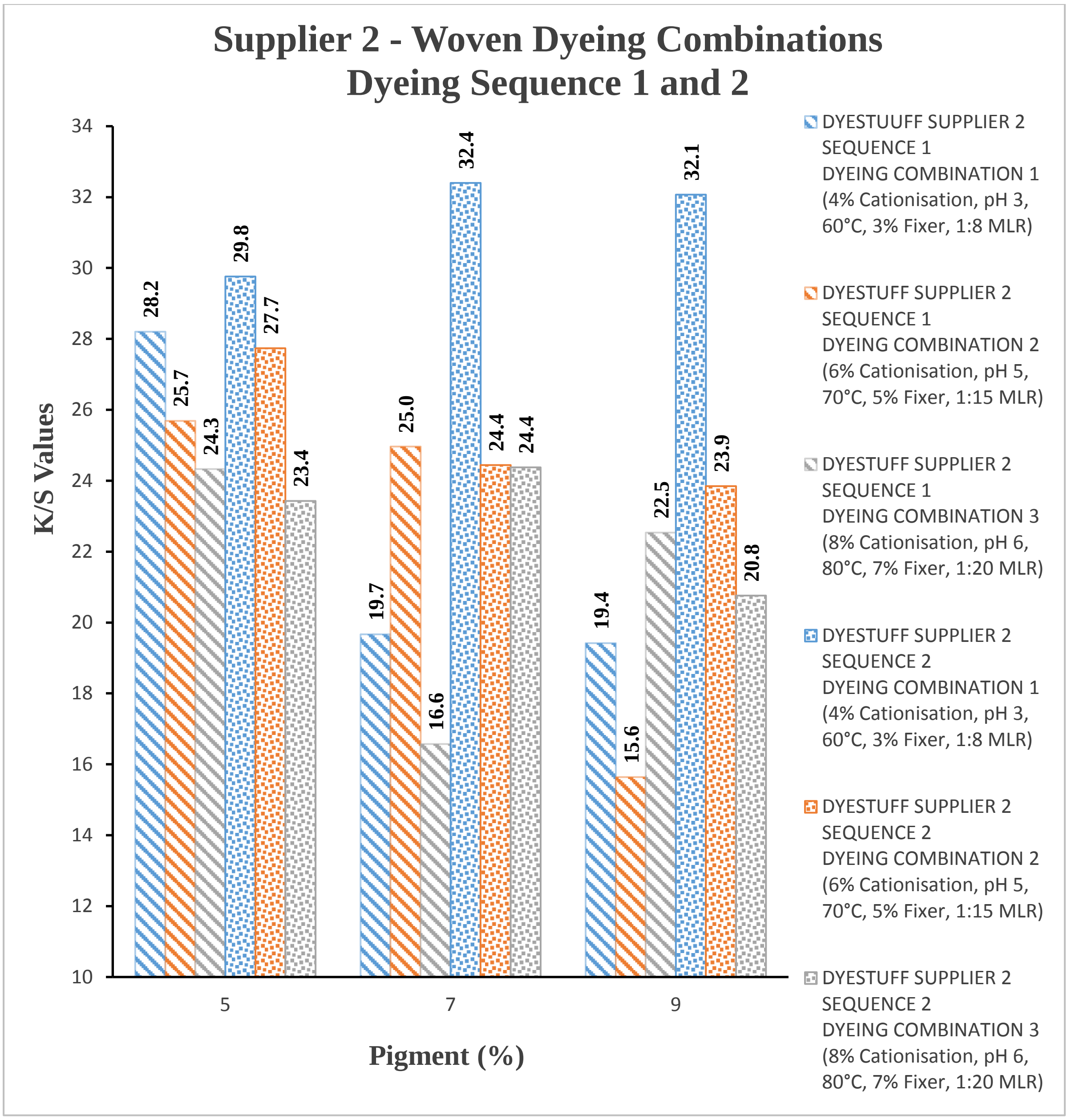


Figure 4.48 Effect of Pigment (%) on K/S for the Dyeing Combinations for Woven Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

Table 4.48, shows that sequence 1 achieves acceptable pass ratings of 3/4 at 7 and 9% pigment for dyeing combination 1; whereas sequence 2, achieves the same at all pigment concentrations for dyeing combination 1 and at 5% pigment for dyeing combination 3. In addition, Figure 4.49 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, only sequence 2 achieves a pass at all pigment levels, with K/S values higher than that for sequence 1.

Table 4.48 Woven Test Results for Pigment Concentration Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
Pigment Trials:							WOVEN										Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	28.2	5	4/5	4/5	5	4/5	3	3	3	2/3	22.4	21.1
	4	3	7	60	3	1:8	19.7	5	5	5	5	5	4/5	4	4	4		
	4	3	9	60	3	1:8	19.4	5	5	5	5	4/5	4/5	4/5	3/4	4		
2	6	5	5	70	5	1:15	25.7	5	5	5	5	4/5	2/3	2/3	2/3	2/3	22.1	
	6	5	7	70	5	1:15	25.0	5	4/5	4/5	5	4/5	3	3	4	4		
	6	5	9	70	5	1:15	15.6	5	5	4/5	5	5	2/3	2/3	3/4	3		
3	8	6	5	80	7	1:20	24.3	5	5	5	5	4/5	3	3	4/5	3	21.1	
	8	6	7	80	7	1:20	16.6	5	5	4/5	5	4/5	3/4	3	3	2/3		
	8	6	9	80	7	1:20	22.5	5	5	5	5	4/5	3	4	3/4	3		
SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Pigment Trials:							WOVEN										Dyeing Combination Averages	Total Pigment Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	29.8	5	5	5	5	5	4	4	3/4	3/4	31.4	26.1
	4	3	7	60	3	1:8	32.4	5	5	5	5	5	4	4/5	3/4	3/4		
	4	3	9	60	3	1:8	32.1	5	5	5	5	5	4/5	4/5	4	4		
2	6	5	5	70	5	1:15	27.7	5	5	5	4/5	4/5	3	2/3	3	4/5	25.3	
	6	5	7	70	5	1:15	24.4	5	5	5	5	5	3/4	3	3	4		
	6	5	9	70	5	1:15	23.9	5	5	5	5	5	3/4	3/4	3	3		
3	8	6	5	80	7	1:20	23.4	5	5	5	5	5	4	3/4	3/4	4	22.9	
	8	6	7	80	7	1:20	24.4	5	5	5	5	5	4/5	4/5	3	3/4		
	8	6	9	80	7	1:20	20.8	5	5	5	5	5	3	3	3	2		

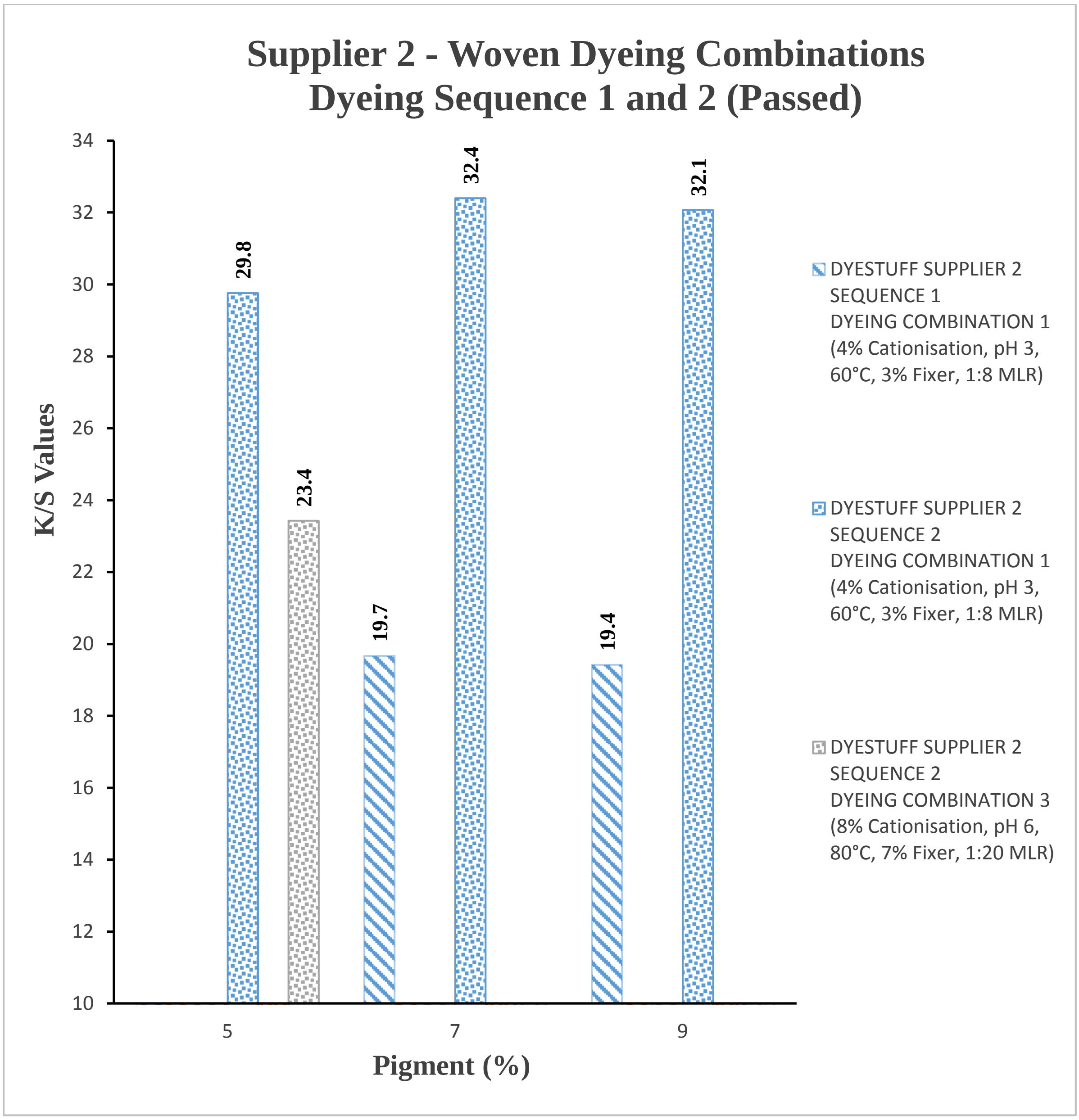


Figure 4.49 Grey Scale Ratings of 3/4 or Higher for Pigment Concentration Trials for Woven Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

4.3.3.8. DISCUSSION

Acceptable pass ratings of 3/4, as indicated in Figures 4.47 and 4.49, showed that sequence 1 obtained pass ratings at 7 and 9% pigment levels, for both knitted and woven fabrics, whereas sequence 2 obtained pass ratings at all pigment levels for both knitted and woven fabrics. In addition, 4 dyeing combinations for the knitted, and 2 for the woven, achieved pass ratings of 4 or higher for all fastness criteria, for sequence 1 and 2. Tables 4.49 and 4.50, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for knitted being K/S of 27.0, and that of woven being K/S of 32.1, both at 9% pigment for dyeing combination 1, sequence 2.

Table 4.49 Ideal Dyeing Combinations for Knitted Fabric for Pigment Concentration Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 2																
Pigment Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	7	60	3	1:8	19.4	5	5	5	5	5	4/5	4	4	4/5
	4	3	9	60	3	1:8	18.8	5	5	5	5	5	4/5	4/5	4/5	4
SEQUENCE 2 - SUPPLIER 2																
Pigment Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	7	60	3	1:8	26.4	5	5	5	5	5	4/5	4	4/5	4
	4	3	9	60	3	1:8	27.0	5	5	5	5	5	4/5	4/5	4/5	4/5

Table 4.50 Ideal Dyeing Combinations for Woven Fabric for Pigment Concentration Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 2																
Pigment Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	7	60	3	1:8	19.7	5	5	5	5	5	4/5	4	4	4
SEQUENCE 2 - SUPPLIER 2																
Pigment Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	9	60	3	1:8	32.1	5	5	5	5	5	4/5	4/5	4	4

4.3.3.9. CONCLUSION

To conclude the results for all pigment concentration trials for each supplier and sequence, the average K/S was taken into account. The effect of pigment concentration on K/S, for both knitted and woven fabrics, for both suppliers and sequences showed a decrease in K/S as the pigment concentration increased from 5 to 7 to 9% for all dyeing combinations, while the remaining 5 parameters (cationisation, pH, temperature, binder/fixer and MLR) increased in their respective levels.

The knitted fabric for Supplier 1 achieved a slightly higher average K/S for dyeing sequence 1 compared to that for dyeing sequence 2, while Supplier 2 achieved a higher K/S for dyeing sequence 2 compared to that for dyeing sequence 1.

The woven fabric, however, achieved a higher K/S for dyeing sequence 2 compared to that for dyeing sequence 1, for both suppliers. Furthermore, both dyeing sequences for Supplier 2, achieved higher average K/S values compared to that for Supplier 1, for both fabrics. In addition, the K/S values for all woven fabric were higher compared to that for the knitted fabric, with the reasons for this difference being explained in section 4.3.7

Taking the K/S values into account, it can be concluded that the ideal pigment concentration for the knitted fabric was at 9% (K/S of 27.0) for sequence 2 for Supplier 2, while that for the woven fabric was at 7% (K/S of 19.7) for sequence 1 for Supplier 2. In addition, these K/S values also achieved Grey Scale ratings of 4 or higher for all fastness criteria. The ideal pigment concentrations, as stated above, contrasts previous works carried out by Patra *et al* (2006), who used pigment concentrations of 1, 2 and 3%, as well as Kumar *et al* (2013), who used 4% pigment, with both works reporting poor wet rub fastness. A drawback, however, of the use of high concentrations of pigments, as used in this research, lead to the adverse staining of the dyeing equipment, which became apparent after approximately 20 dyeings were completed.

4.3.4. Effect of Temperature Level

The two dyestuff suppliers were compared with one another to determine the effect of temperature on the outcome of K/S and fastness, when the temperature levels were increased from 60ºC to 70ºC to 80ºC, while the other 5 parameters (cationisation, pH, pigment, binder/fixer and MLR) were kept constant, per dyeing combination. The temperature level trials consisted of three dyeing combinations, with 3 trials per dyeing combination, and were performed using dyeing sequence 1 and 2. The results from these trials for both suppliers and sequences will be concluded in section 4.3.7. The dyeing combinations used in the temperature level trials are presented in Table 4.51, with the results presented graphically.

Table 4.51 Dyeing Combinations for Temperature Level Trials.

	Temperature Level Trials						
	Cationisation (%)	**pH**	**Pigment (%)**	**Temp (°C)**	**Binder/ Fixer (%)**	**MLR**	**Trial No.**
Combination 1	4	3	5	60	3	1:8	1
	4	3	5	70	3	1:8	4
	4	3	5	80	3	1:8	7
Combination 2	6	5	7	60	5	1:15	2
	6	5	7	70	5	1:15	5
	6	5	7	80	5	1:15	8
Combination 3	8	6	9	60	7	1:20	3
	8	6	9	70	7	1:20	6
	8	6	9	80	7	1:20	9

4.3.4.1. SUPPLIERS 1 AND 2 (DYEING SEQUENCE 1)

4.3.4.1.1. Knitted Fabric Results

The K/S for both suppliers is represented in Figure 4.50, which shows that the K/S for Supplier 2 is higher than that for Supplier 1; with the greatest K/S observed at a temperature of 60°C. Supplier 1, shows a decrease in K/S, for all dyeing combinations, at each temperature level, as the remaining parameters are increased, with Supplier 2 exhibiting the same trend at 60º and 70°C. Furthermore, Supplier 1 for dyeing combination 2, shows a decrease in K/S, as the temperature level is increased from 60º to 70º to 80°C, with the same trend observed for Supplier 2 at dyeing combination 1.

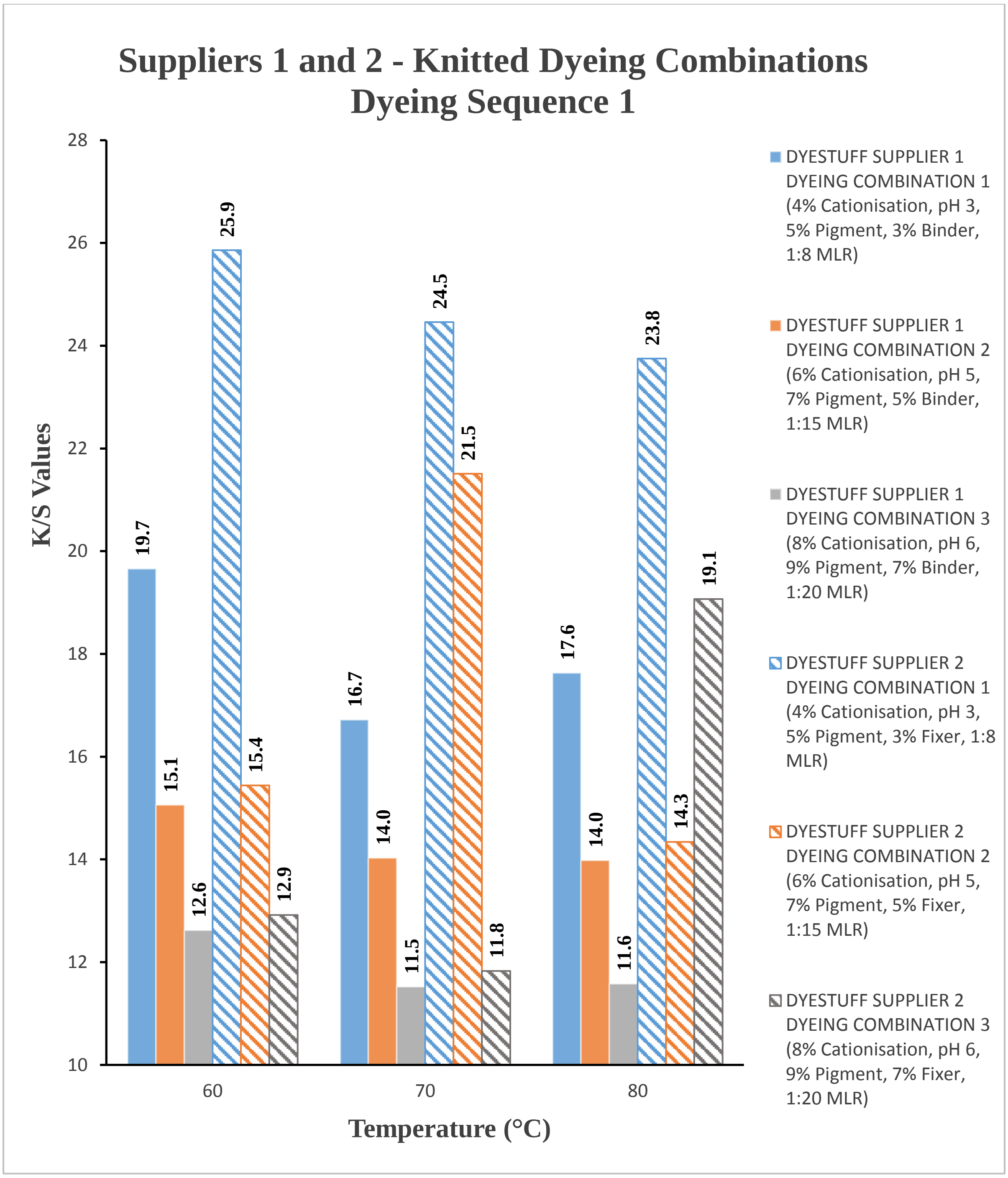


Figure 4.50 Effect of Temperature (°C) on K/S for the Dyeing Combinations for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

Table 4.52, shows that Supplier 1 achieves acceptable pass ratings of 3/4 at 70º and 80ºC for dyeing combination 1, and at all temperature levels for dyeing combinations 2 and 3, while Supplier 2, achieves acceptable pass ratings at 60ºC for dyeing combinations 2 and 3. In addition, Figure 4.51 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4, with the corresponding K/S for Supplier 1 being relatively low.

Table 4.52 Knitted Test Results for Temperature Level Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
Temperature Trials:							KNITTED										Dyeing Combination Averages	Total Temperature Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	19.7	4/5	3/4	4/5	3	3/4	2/3	2/3	2	2/3	18.0	14.1
	4	3	5	70	3	1:8	16.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
	4	3	5	80	3	1:8	17.6	4/5	4/5	4/5	5	5	4	4	4	3/4		
2	6	5	7	60	5	1:15	15.1	4/5	4/5	4/5	4/5	4/5	4	4	4	4	14.4	
	6	5	7	70	5	1:15	14.0	5	4/5	4/5	4/5	4/5	4	3/4	4	4		
	6	5	7	80	5	1:15	14.0	4/5	5	5	4/5	4/5	4	4	4	4		
3	8	6	9	60	7	1:20	12.6	4/5	5	5	4/5	4/5	4	4	4	4	11.9	
	8	6	9	70	7	1:20	11.5	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4		
SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
Temperature Trials:							KNITTED										Dyeing Combination Averages	Total Temperature Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.9	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3	24.7	17.9
	4	3	5	70	3	1:8	24.5	5	4/5	4	4	2	2	2	2/3	2/3		
	4	3	5	80	3	1:8	23.8	5	4	4	4	4	2/3	2	2	2		
2	6	5	7	60	5	1:15	15.4	5	5	5	5	5	4/5	4/5	4/5	4/5	17.1	
	6	5	7	70	5	1:15	21.5	5	4/5	5	5	4/5	3/4	3	3	3		
	6	5	7	80	5	1:15	14.3	5	4/5	4/5	4/5	4/5	2/3	2/3	2/3	2/3		
3	8	6	9	60	7	1:20	12.9	5	5	5	5	5	4	5	4	4	14.6	
	8	6	9	70	7	1:20	11.8	5	4/5	4/5	5	4/5	2/3	1/2	2	2/3		
	8	6	9	80	7	1:20	19.1	5	4/5	4/5	5	5	2/3	2/3	2/3	3		

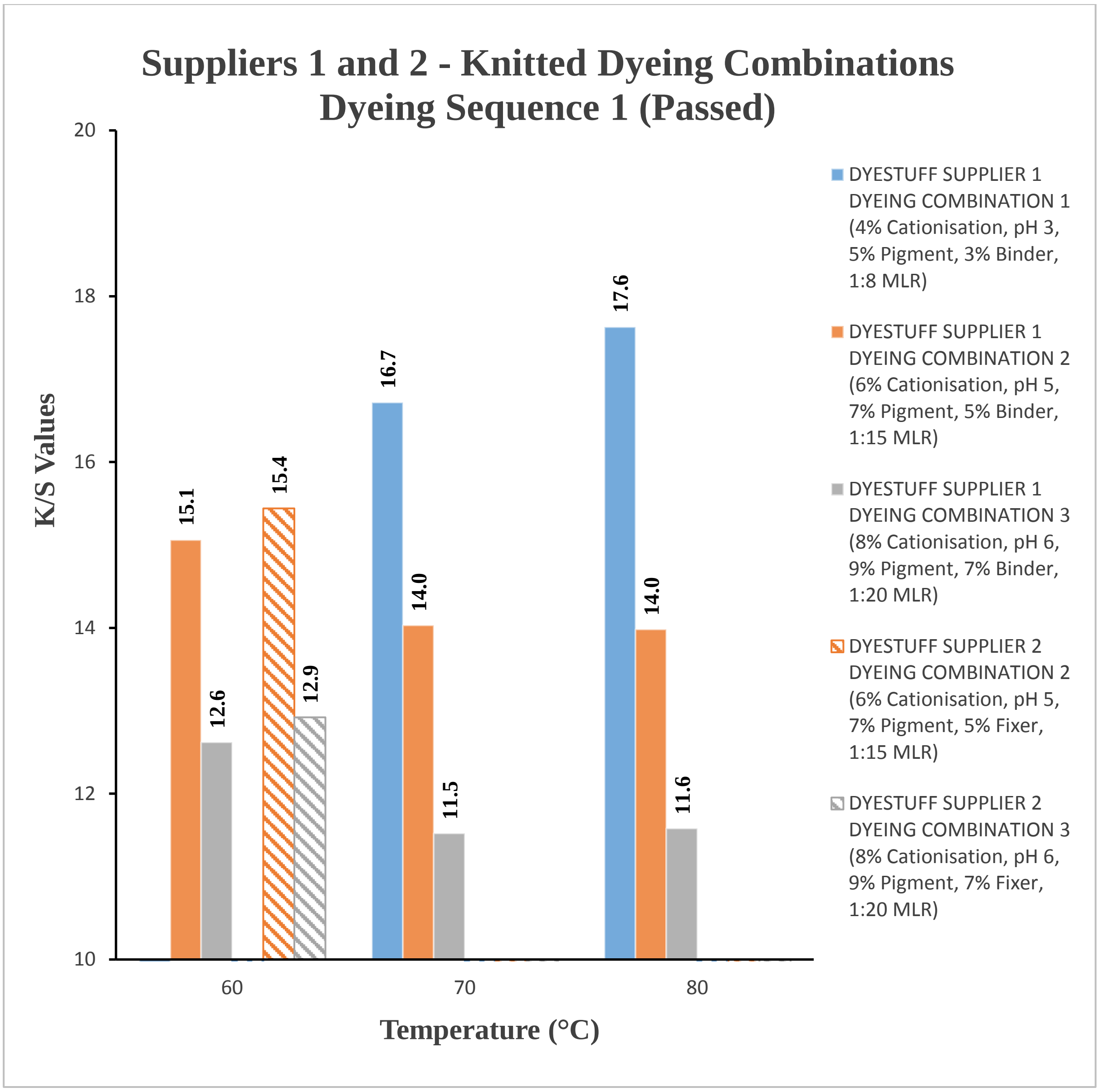


Figure 4.51 Grey Scale Ratings of 3/4 or Higher for Temperature Level Trials for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

4.3.4.1.2. Woven Fabric Results

The K/S for both suppliers is represented in Figure 4.52, which shows that the K/S, for Supplier 2 is greater than that for Supplier 1; with the highest K/S observed at 60°C. Suppliers 1 and 2, show a decrease in K/S at each temperature level, as the remaining parameters are increased. Furthermore Supplier 1, shows a decrease in K/S, for dyeing combination 3, as the temperature increases from 60° to 70° to 80°C.

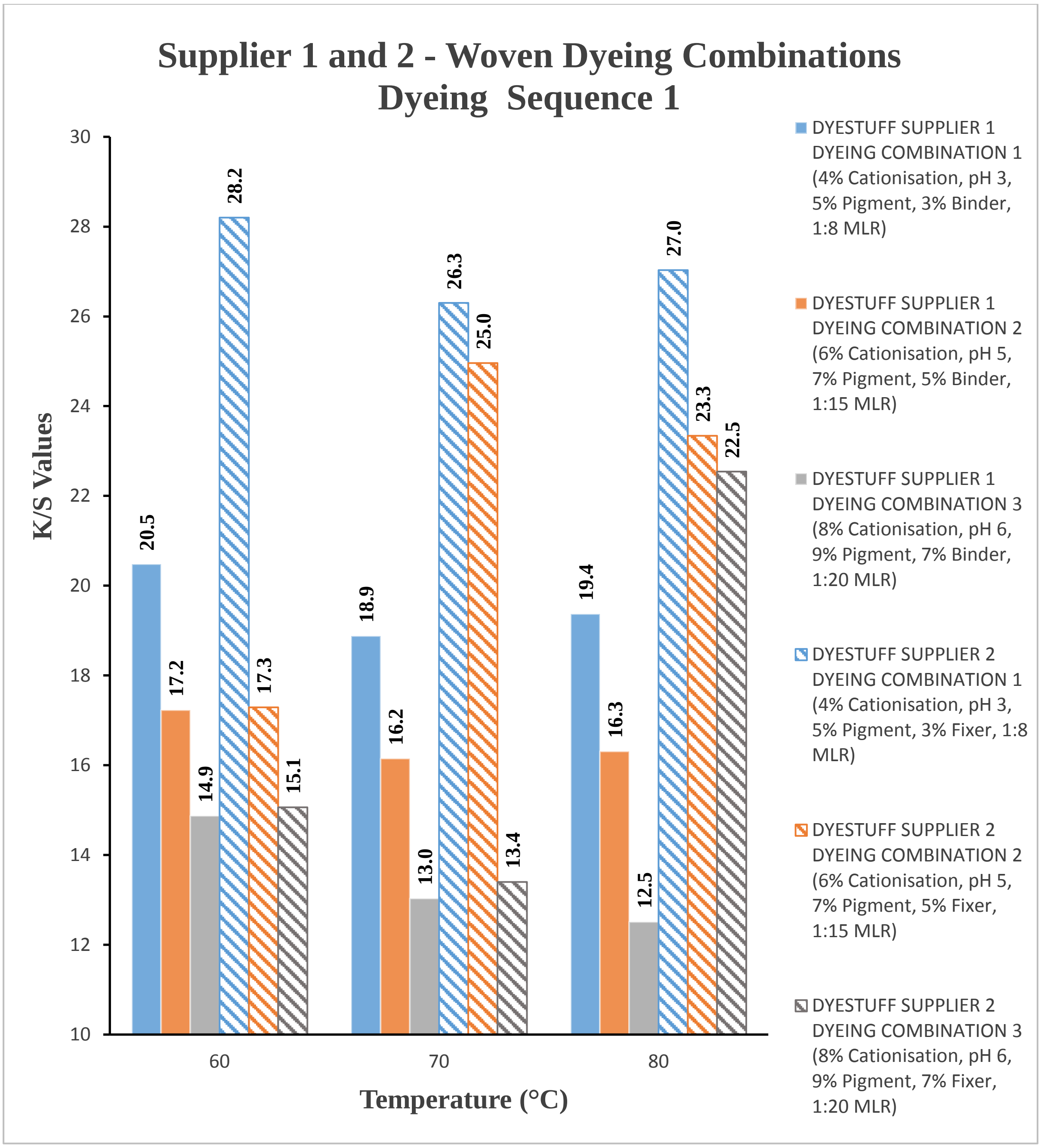


Figure 4.52 Effect of Temperature (°C) on K/S for the Dyeing Combinations for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

Table 4.53, shows that Supplier 1 achieves acceptable pass ratings of 3/4 at all temperature levels for all dyeing combinations, whereas Supplier 2, achieves the same at 60ºC for dyeing combination 2 and 3. In addition, Figure 4.53 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4, with the corresponding K/S values being relatively lower than that for Supplier 2.

Table 4.53 Woven Test Results for Temperature Level Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
Temperature Trials:							WOVEN										Dyeing Combination Averages	Total Temperature Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub Face	Warp Dry Rub Back	Weft Dry Rub Face	Weft Dry Rub Back	Warp Wet Rub Face	Warp Wet Rub Back	Weft Wet Rub Face	Weft Wet Rub Back		
1	4	3	5	60	3	1:8	20.5	4/5	4/5	4/5	4/5	4/5	4	4/5	3/4	4	19.6	16.0
	4	3	5	70	3	1:8	18.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
	4	3	5	80	3	1:8	19.4	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
2	6	5	7	60	5	1:15	17.2	4/5	4/5	4/5	4	4/5	4	4	4	4	16.6	
	6	5	7	70	5	1:15	16.2	5	4/5	4/5	4/5	4/5	4/5	4/5	4	3/4		
	6	5	7	80	5	1:15	16.3	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
3	8	6	9	60	7	1:20	14.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4	13.5	
	8	6	9	70	7	1:20	13.0	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4		
SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
Temperature Trials:							WOVEN										Dyeing Combination Averages	Total Temperature Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub Face	Warp Dry Rub Back	Weft Dry Rub Face	Weft Dry Rub Back	Warp Wet Rub Face	Warp Wet Rub Back	Weft Wet Rub Face	Weft Wet Rub Back		
1	4	3	5	60	3	1:8	28.2	5	4/5	4/5	5	4/5	3	3	3	2/3	27.2	21.2
	4	3	5	70	3	1:8	26.3	5	4/5	4/5	4/5	4/5	4	2/3	2	2/3		
	4	3	5	80	3	1:8	27.0	5	4/5	4/5	4/5	4/5	4	3	2/3	2/3		
2	6	5	7	60	5	1:15	17.3	5	5	5	5	5	4/5	4/5	3/4	3/4	21.9	
	6	5	7	70	5	1:15	25.0	5	4/5	4/5	5	4/5	3	3	4	4		
	6	5	7	80	5	1:15	23.3	5	5	5	4/5	4/5	3	4	3	3		
3	8	6	9	60	7	1:20	15.1	5	5	5	5	5	4/5	4/5	3/4	4	17.0	
	8	6	9	70	7	1:20	13.4	5	5	4/5	4/5	4/5	3	3/4	3	3		
	8	6	9	80	7	1:20	22.5	5	5	5	5	4/5	3	3	3/4	3		

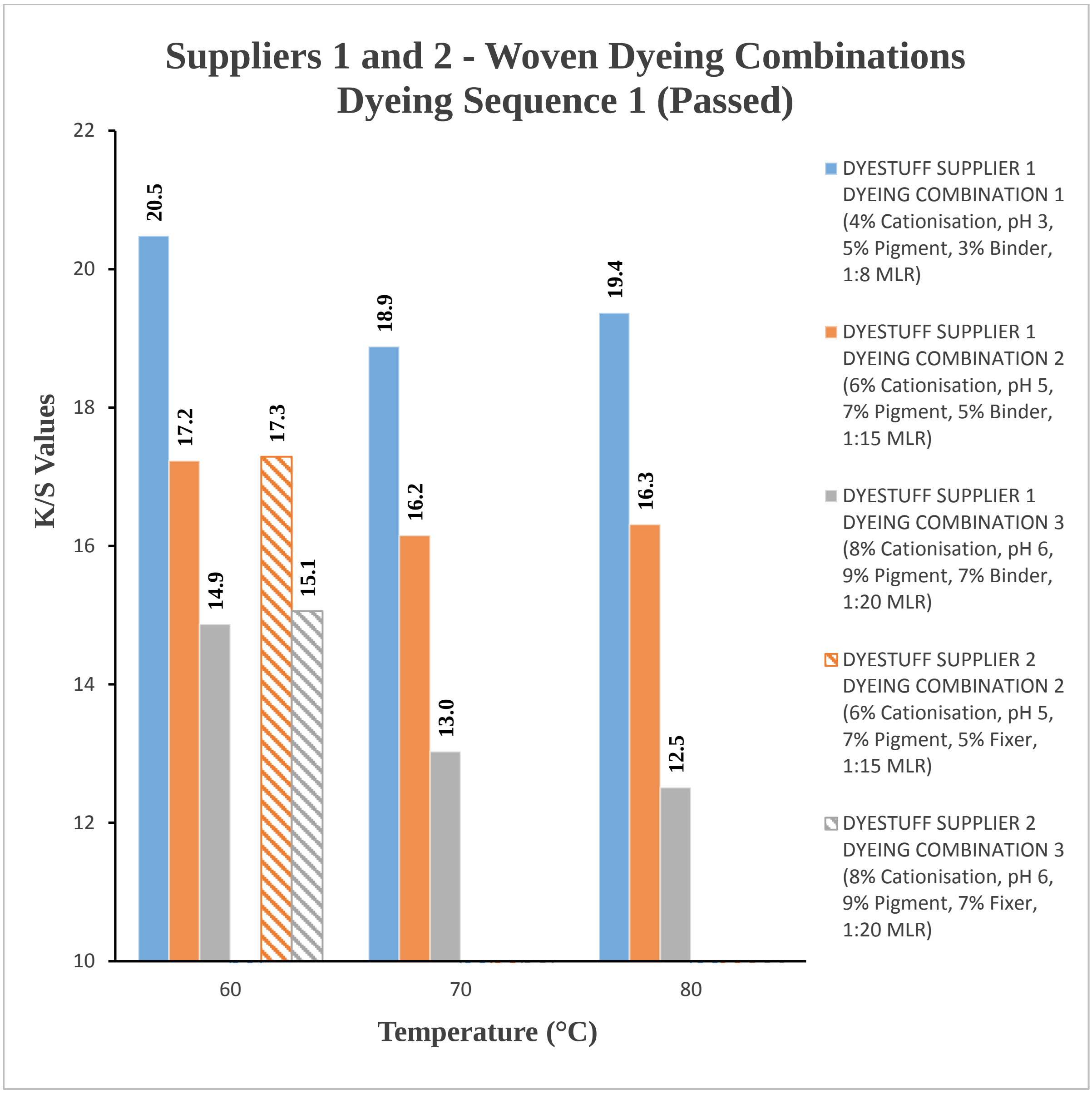


Figure 4.53 Grey Scale Ratings of 3/4 or Higher for Temperature Level Trials for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

4.3.4.2. DISCUSSION

Supplier 2 obtained a higher K/S for both fabrics, than that for Supplier 1, with acceptable pass ratings of 3/4, as indicated in Figures 4.51 and 4.53, which showed that Supplier 1, for both fabrics, obtained pass ratings at all temperature levels, whereas Supplier 2 obtained pass ratings, for both fabrics, at 60ºC for dyeing combinations 2 and 3. In addition, 8 dyeing combinations, for the knitted, and 7 for the woven, achieved pass ratings of 4 or higher for all fastness criteria. Tables 4.54 and 4.55, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for knitted being K/S of 16.7 at 70ºC, and the woven 19.4 at 80ºC, both for dyeing combination 1, Supplier 1.

Table 4.54 Ideal Dyeing Combinations for Knitted Fabric for Temperature Level Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - SUPPLIER 1																
Temperature Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	70	3	1:8	16.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4
2	6	5	7	60	5	1:15	15.1	4/5	4/5	4/5	4/5	4/5	4	4	4	4
	6	5	7	80	5	1:15	14.0	4/5	5	5	4/5	4/5	4	4	4	4
3	8	6	9	60	7	1:20	12.6	4/5	5	5	4/5	4/5	4	4	4	4
	8	6	9	70	7	1:20	11.5	4/5	4/5	4/5	4/5	4/5	4	4	4	4
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4
SEQUENCE 1 - SUPPLIER 2																
Temperature Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
2	6	5	7	60	5	1:15	15.4	5	5	5	5	5	4/5	4/5	4/5	4/5
3	8	6	9	60	7	1:20	12.9	5	5	5	5	5	4	5	4	4

Table 4.55 Ideal Dyeing Combinations for Woven Fabric for Temperature Level Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - SUPPLIER 1																
Temperature Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	70	3	1:8	18.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4
	4	3	5	80	3	1:8	19.4	4/5	4/5	4/5	4/5	4/5	4	4	4	4
2	6	5	7	60	5	1:15	17.2	4/5	4/5	4/5	4	4/5	4	4	4	4
	6	5	7	80	5	1:15	16.3	4/5	4/5	4/5	4/5	4/5	4	4	4	4
3	8	6	9	60	7	1:20	14.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4
	8	6	9	70	7	1:20	13.0	4/5	4/5	4/5	4/5	4/5	4	4	4	4
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4

4.3.4.3. SUPPLIERS 1 AND 2 (DYEING SEQUENCE 2)

4.3.4.3.1. Knitted Fabric Results

The K/S for both suppliers is represented in Figure 4.54, with the highest K/S seen at 60°C for Supplier 2. All dyeing combinations for Suppliers 1 and 2, show a decrease in K/S at each temperature level, as the remaining parameters are increased. Furthermore, all dyeing combinations for Suppliers 1 and 2 show a decrease in K/S as the temperature level is increased from 60º to 70º to 80°C.

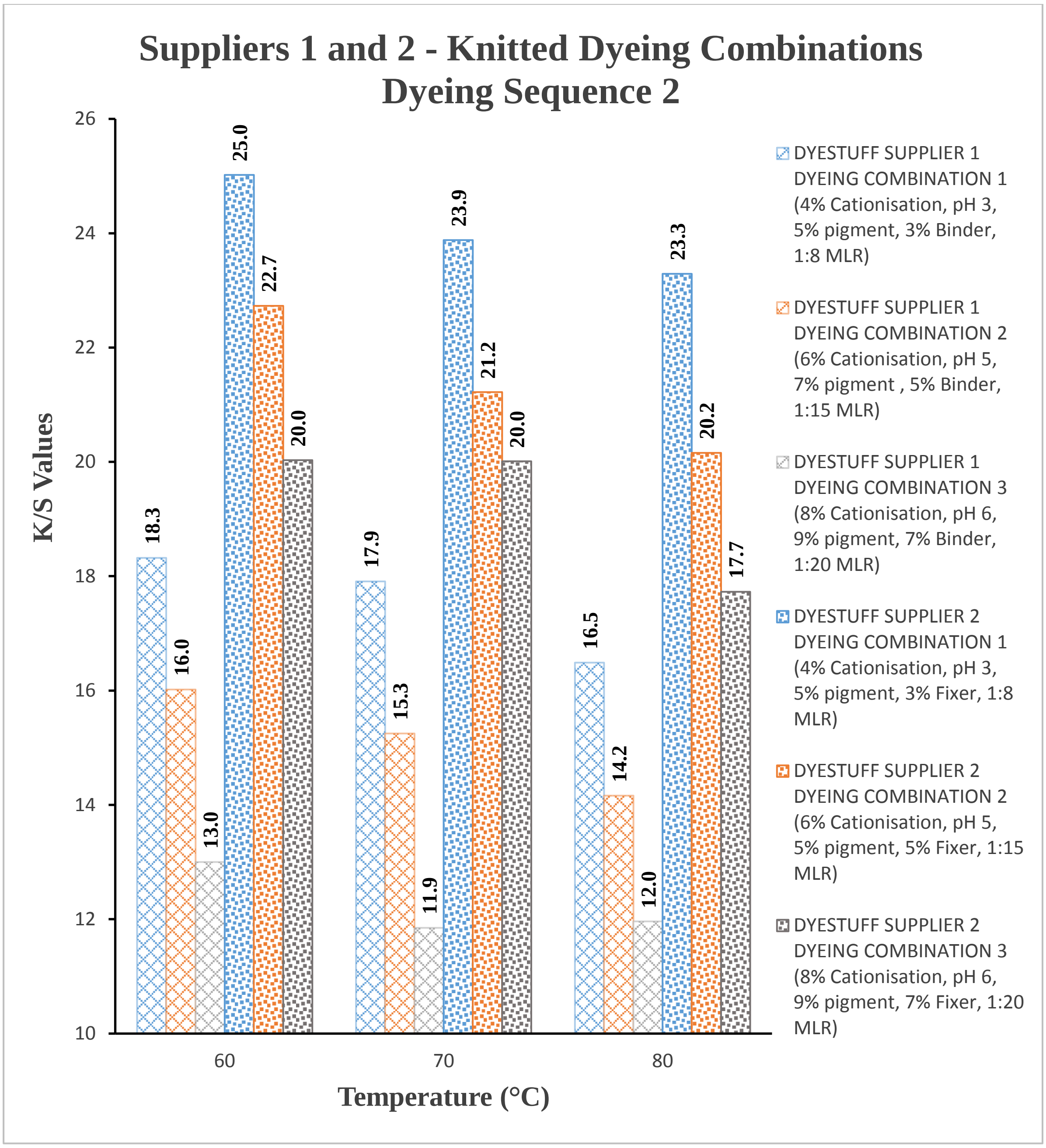


Figure 4.54 Effect of Temperature (°C) on K/S for the Dyeing Combinations for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

Table 4.56, shows that Supplier 1 does not achieves acceptable pass ratings of 3/4 at all dyeing combinations for temperature, whereas Supplier 2 achieves the same at 60ºC for dyeing combinations 1 and 3. In addition, Figure 4.55 shows the dyeing combinations that have passed in terms of all fastness with a rating of 3/4. Accordingly, only Supplier 2 has achieved a pass at 60ºC, with a high K/S value.

Table 4.56 Knitted Test Results for Temperature Level Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Temperature Trials:							KNITTED										Dyeing	Total
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub		Combination Averages	Temperature Average
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	18.3	5	4	4	4	4	2/3	2/3	2/3	3	17.6	14.6
	4	3	5	70	3	1:8	17.9	5	4/5	4	4/5	4	3	2/3	2/3	3		
	4	3	5	80	3	1:8	16.5	5	4/5	4	4/5	4/5	3	3	3	3		
2	6	5	7	60	5	1:15	16.0	5	5	5	4/5	4/5	2/3	2	3	3	15.1	
	6	5	7	70	5	1:15	15.3	5	4/5	4/5	4/5	4/5	3/4	3	3	3		
	6	5	7	80	5	1:15	14.2	5	4/5	4/5	4/5	4/5	2/3	2/3	3	2/3		
3	8	6	9	60	7	1:20	13.0	4/5	5	5	4/5	4/5	3	3	3	3	12.3	
	8	6	9	70	7	1:20	11.9	5	4/5	4/5	4/5	4/5	2/3	2/3	3	2/3		
	8	6	9	80	7	1:20	12.0	5	4/5	4/5	4/5	4/5	3	3	3	3		
SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Temperature Trials:							KNITTED										Dyeing	Total
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub		Combination Averages	Temperature Average
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.0	5	4/5	5	5	5	3/4	4	4	4	24.1	21.1
	4	3	5	70	3	1:8	23.9	5	4/5	4/5	4/5	4/5	3	2/3	3	3		
	4	3	5	80	3	1:8	23.3	5	4/5	4/5	4/5	5	3	3	3/4	3		
2	6	5	7	60	5	1:15	22.7	5	5	5	5	5	4	3	3	3	21.4	
	6	5	7	70	5	1:15	21.2	5	4	4	4/5	4/5	2/3	2/3	2	3		
	6	5	7	80	5	1:15	20.2	4/5	4/5	5	5	4/5	3	3/4	4/5	4/5		
3	8	6	9	60	7	1:20	20.0	5	4/5	4/5	4/5	4/5	3/4	4	3/4	3/4	19.3	
	8	6	9	70	7	1:20	20.0	5	5	5	5	5	3	3	3/4	3/4		
	8	6	9	80	7	1:20	17.7	5	4/5	4/5	5	4/5	2/3	2	2	2/3		

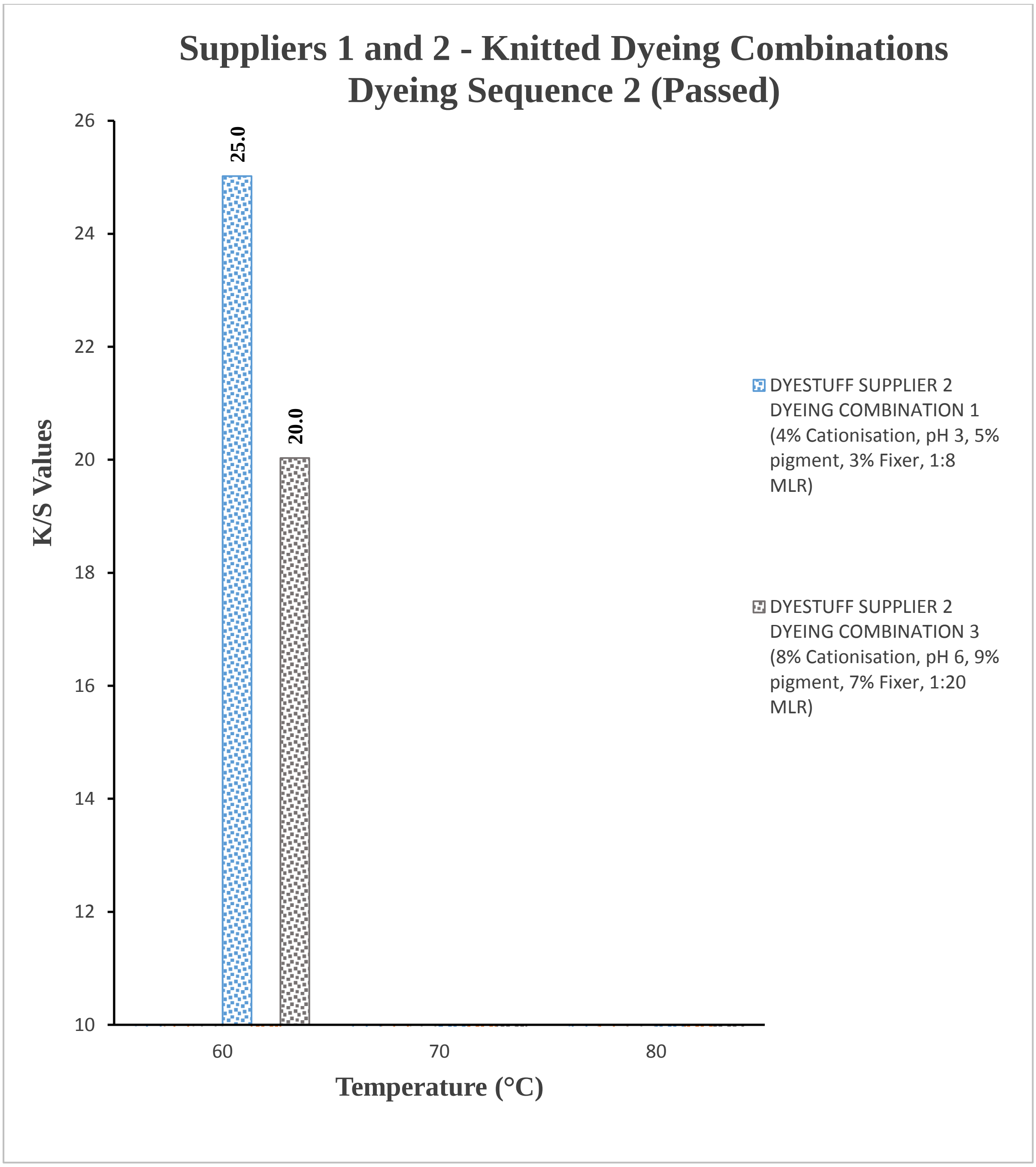


Figure 4.55 Grey Scale Ratings of 3/4 or Higher for Temperature Level Trials for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

4.3.4.3.2. <u>Woven Fabric Results</u>

The K/S for both suppliers is represented in Figure 4.56, with the greatest K/S observed at 70°C. All dyeing combinations for Supplier 2, show a decrease in K/S at each pH level, as the remaining parameters are increased; with Supplier 1 exhibiting this trend at 80°C. A decrease in K/S is also visible for all dyeing combinations for Supplier 1, and for dyeing combination 2 for Supplier 2, as the temperature level is increased from 70° to 80°C.

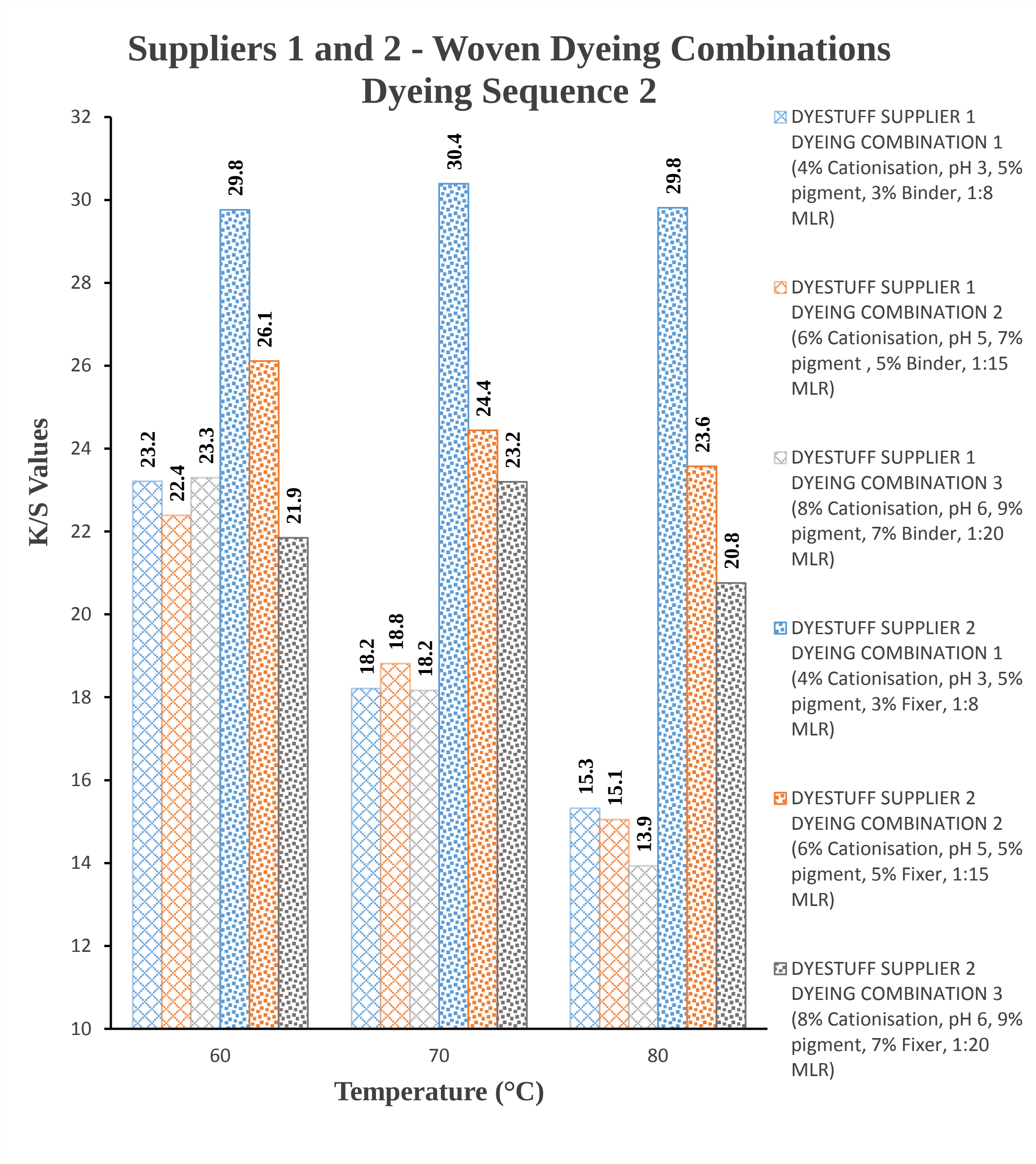


Figure 4.56 Effect of Temperature Level (°C) on K/S for the Dyeing Combinations for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

Table 4.57, shows that Supplier 1 achieves acceptable pass ratings of 3/4 at 70º and 80ºC for dyeing combinations 1, and at 80°C for dyeing combination 2. Supplier 2, achieves acceptable pass ratings at all temperature levels for dyeing combination 1, and at 60°C for dyeing combination 2 and 3. In addition, Figure 4.57 shows the dyeing combinations that have passed in terms of all fastness with a rating of 3/4. Accordingly, both suppliers achieved a pass, however, with Supplier 2 achieving higher K/S values than that for Supplier 1.

Table 4.57 Woven Test Results for Temperature Level Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Temperature Trials:							WOVEN										Dyeing Combination Averages	Total Temperature Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	23.2	5	4/5	4/5	4/5	4/5	3	3	3	3	23.0	17.9
	4	3	5	70	3	1:8	22.4	5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3/4		
	4	3	5	80	3	1:8	23.3	5	4/5	4/5	4/5	4/5	4	4	4	3/4		
2	6	5	7	60	5	1:15	18.2	5	4/5	4/5	4/5	4/5	4	3/4	3	3	18.4	
	6	5	7	70	5	1:15	18.8	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3/4		
	6	5	7	80	5	1:15	18.2	5	4/5	4/5	4/5	4/5	4	3/4	4	3/4		
3	8	6	9	60	7	1:20	15.3	5	5	5	5	5	3/4	3	3	3	14.1	
	8	6	9	70	7	1:20	13.1	5	4/5	4/5	4/5	4/5	3	3	3	3		
	8	6	9	80	7	1:20	13.9	4/5	4/5	4/5	4/5	4/5	3/4	3	3	3		

SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Temperature Trials:							WOVEN										Dyeing Combination Averages	Total Temperature Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	29.8	5	5	5	5	5	4	4	3/4	3/4	30.0	25.0
	4	3	5	70	3	1:8	30.4	5	5	5	5	5	4/5	4	3/4	4		
	4	3	5	80	3	1:8	29.8	5	5	5	5	5	4	4	3/4	3/4		
2	6	5	7	60	5	1:15	26.1	5	5	5	5	5	4/5	4	3/4	3/4	24.7	
	6	5	7	70	5	1:15	24.4	5	5	5	5	5	3/4	3	3	4		
	6	5	7	80	5	1:15	23.6	5	5	5	5	4	3/4	3	3	3/4		
3	8	6	9	60	7	1:20	21.9	5	5	5	4/5	5	4/5	4	4	4	21.9	
	8	6	9	70	7	1:20	23.2	5	5	5	5	5	3/4	3/4	4	3		
	8	6	9	80	7	1:20	20.8	5	5	5	5	5	3	3	3	2		

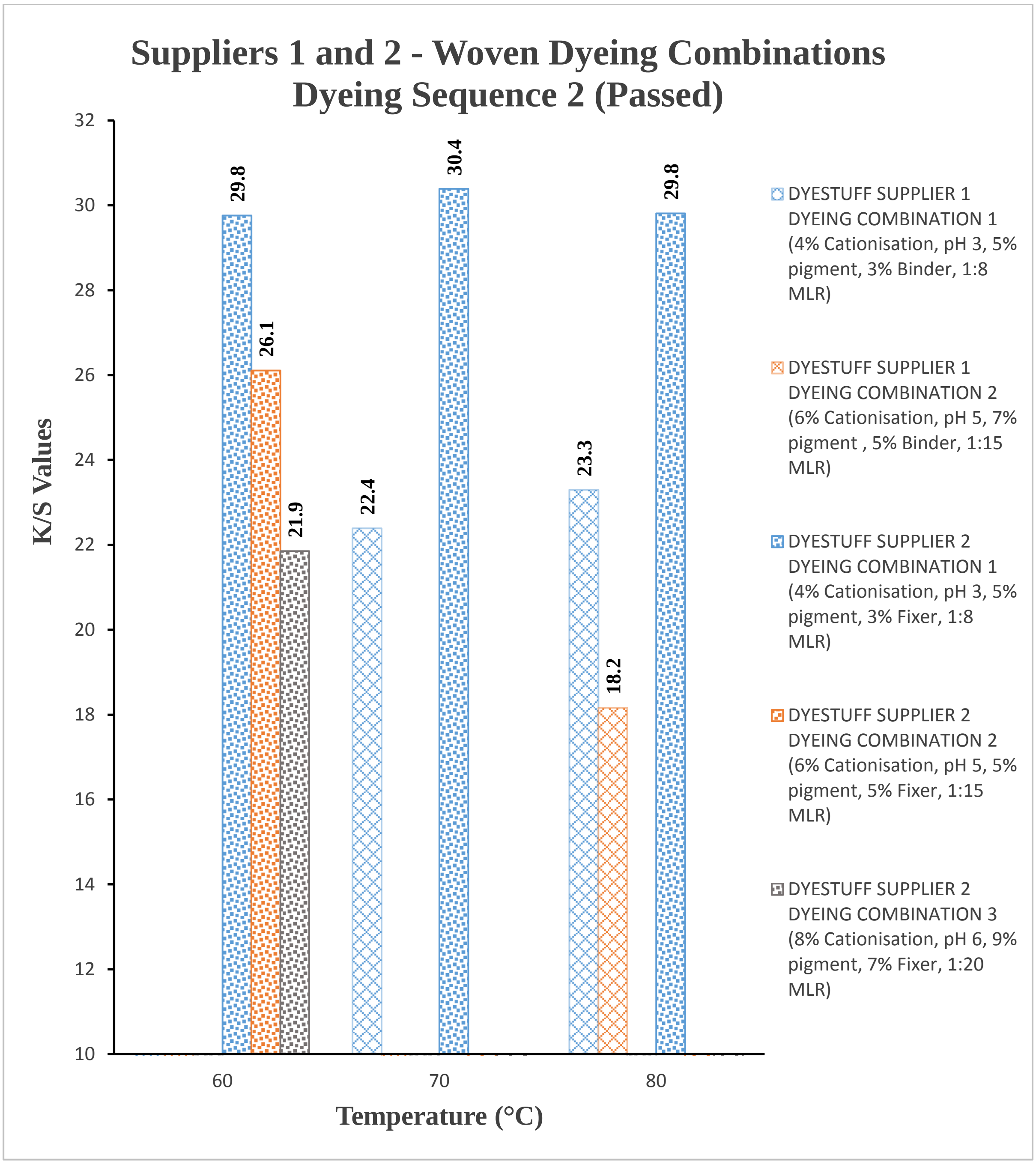


Figure 4.57 Grey Scale Ratings of 3/4 or Higher for Temperature Level Trials for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

4.3.4.4. DISCUSSION

Supplier 2 obtained a higher K/S for both fabrics, than that for Supplier 1, with acceptable pass ratings of 3/4, as indicated in Figures 4.55 and 4.57, which showed that Supplier 1 only obtained pass ratings at 70° and 80 ºC for the woven fabric, while Supplier 2 obtained pass ratings at 60ºC for the knitted fabric, and passed at all temperature levels for the woven. In addition, only Supplier 2 for the woven fabric achieved 1 dyeing combination with a pass rating of 4 or higher for all fastness criteria. Table 4.58, represents the dyeing combination that achieved a Grey Scale rating of 4 or higher, with the ideal choice being K/S of 21.9 at 60°C dyeing combination 3, sequence 2, Supplier 2.

Table 4.58 Ideal Dyeing Combinations for Woven Fabric for Temperature Level for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - SUPPLIER 2																
Temperature Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
3	8	6	9	60	7	1:20	21.9	5	5	5	4/5	5	4/5	4	4	4

4.3.4.5. SUPPLIER 1 (DYEING SEQUENCE 1 AND 2)

4.3.4.5.1. Knitted Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.58, with the highest K/S seen at 60°C for dyeing sequence 1. All dyeing combinations for sequence 1 and 2, show a decrease in K/S at each temperature level, as the level of the remaining parameters are increased. Sequence 1, for dyeing combination 2, show a decrease in K/S as the temperature is increased from 60º to 70º to 80°C, with the same trend observed for dyeing combinations 1 and 2, sequence 2.

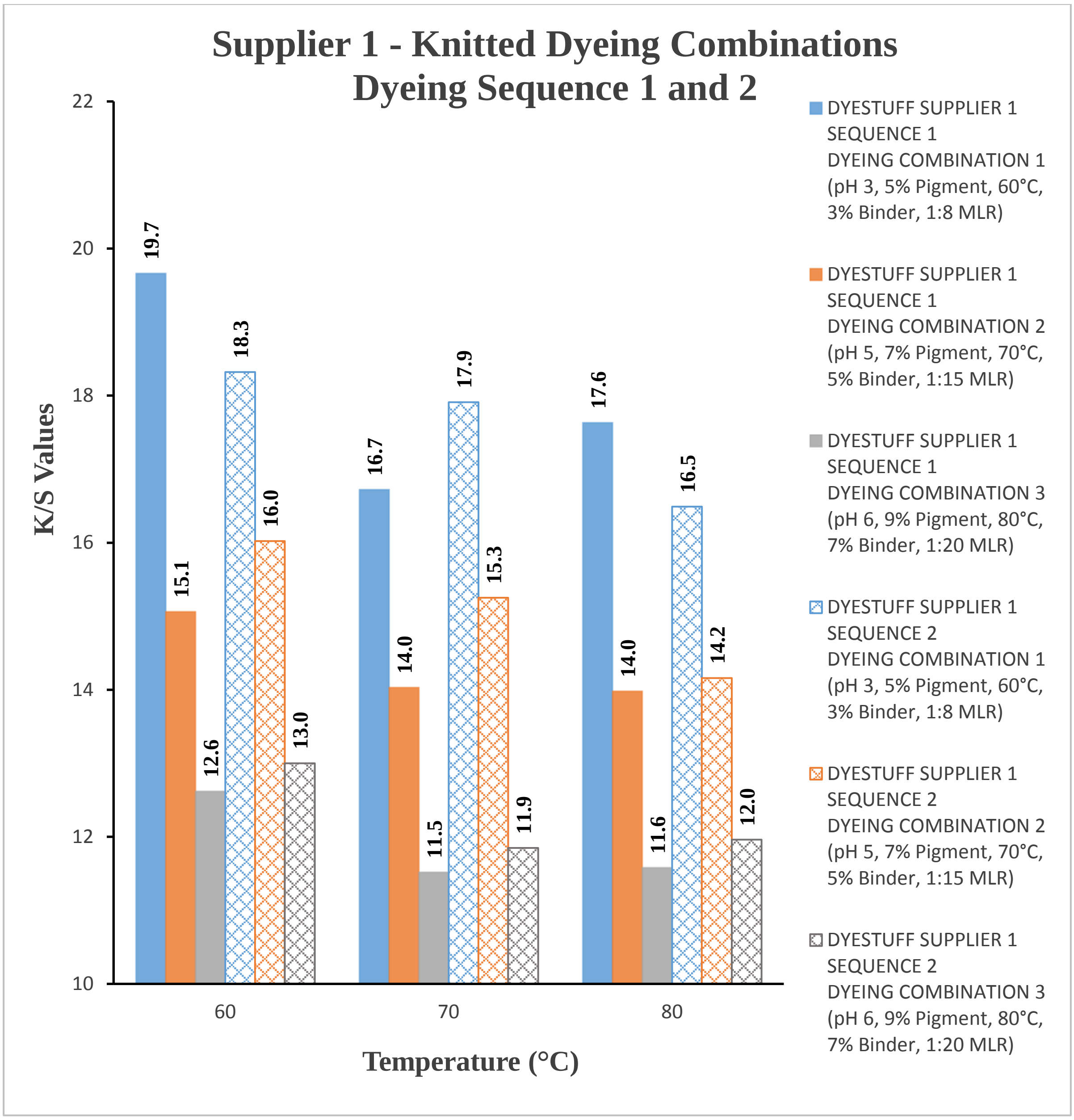


Figure 4.58 Effect of Temperature (°C) on K/S for the Dyeing Combinations for Knitted Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

Table 4.59, shows that sequence 1 achieves acceptable pass ratings of 3/4 at 70º and 80˚C for dyeing combination 1, and at all temperature levels for dyeing combination 2 and 3; while sequence 2 does not achieve any pass ratings at all temperature levels for all dyeing combinations. In addition, Figure 4.59 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, only sequence 1 achieved a pass at all temperature levels, however with K/S values slightly lower than that for sequence 2.

Table 4.59 Knitted Test Results for Temperature Level Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
Temperature Trials:							KNITTED										Dyeing Combination Averages	Total Temperature Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	19.7	4/5	3/4	4/5	3	3/4	2/3	2/3	2	2/3	18.0	14.1
	4	3	5	70	3	1:8	16.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
	4	3	5	80	3	1:8	17.6	4/5	4/5	4/5	5	5	4	4	4	3/4		
2	6	5	7	60	5	1:15	15.1	4/5	4/5	4/5	4/5	4/5	4	4	4	4	14.4	
	6	5	7	70	5	1:15	14.0	5	4/5	4/5	4/5	4/5	4	3/4	4	4		
	6	5	7	80	5	1:15	14.0	4/5	5	5	4/5	4/5	4	4	4	4		
3	8	6	9	60	7	1:20	12.6	4/5	5	5	4/5	4/5	4	4	4	4	11.9	
	8	6	9	70	7	1:20	11.5	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4		
SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Temperature Trials:							KNITTED										Dyeing Combination Averages	Total Temperature Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	18.3	5	4	4	4	4	2/3	2/3	2/3	3	17.6	14.6
	4	3	5	70	3	1:8	17.9	5	4/5	4	4/5	4	3	2/3	2/3	3		
	4	3	5	80	3	1:8	16.5	5	4/5	4	4/5	4/5	3	3	3	3		
2	6	5	7	60	5	1:15	16.0	5	5	5	4/5	4/5	2/3	2	3	3	15.1	
	6	5	7	70	5	1:15	15.3	5	4/5	4/5	4/5	4/5	3/4	3	3	3		
	6	5	7	80	5	1:15	14.2	5	4/5	4/5	4/5	4/5	2/3	2/3	3	2/3		
3	8	6	9	60	7	1:20	13.0	4/5	5	5	4/5	4/5	3	3	3	3	12.3	
	8	6	9	70	7	1:20	11.9	5	4/5	4/5	4/5	4/5	2/3	2/3	3	2/3		
	8	6	9	80	7	1:20	12.0	5	4/5	4/5	4/5	4/5	3	3	3	3		

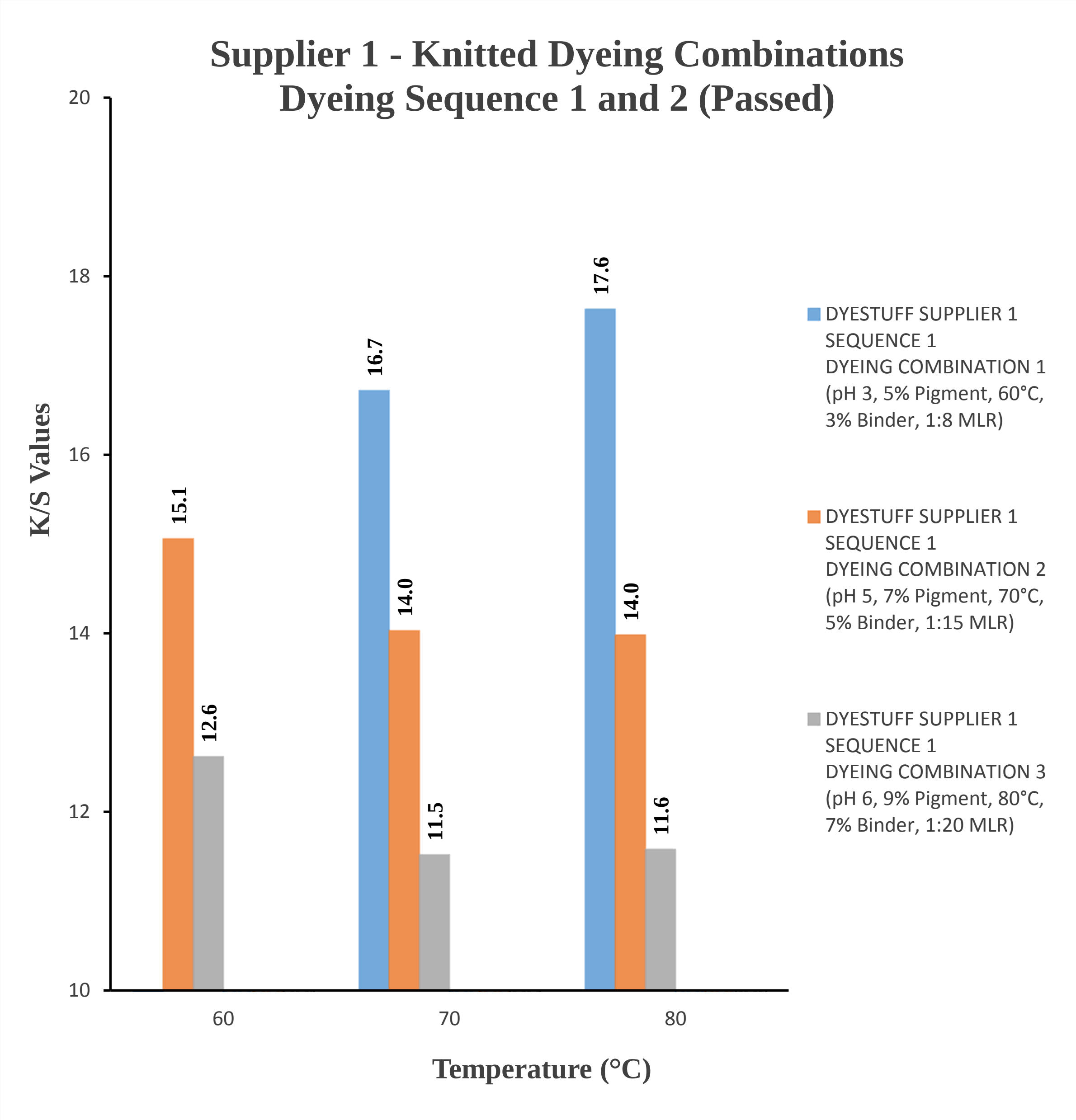


Figure 4.59 Grey Scale Ratings of 3/4 or Higher for Temperature Level Trials for Knitted Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

4.3.4.5.2. Woven Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.60, with the highest K/S seen at 80°C for dyeing sequence 2. All dyeing combinations for sequence 1 and 2, show a decrease in K/S at all temperature levels, as the level of the remaining parameters are increased. The only visible trend is a decrease in K/S for dyeing combination 2, sequence 1, as the temperature is increased from 60º to 70º to 80°C.

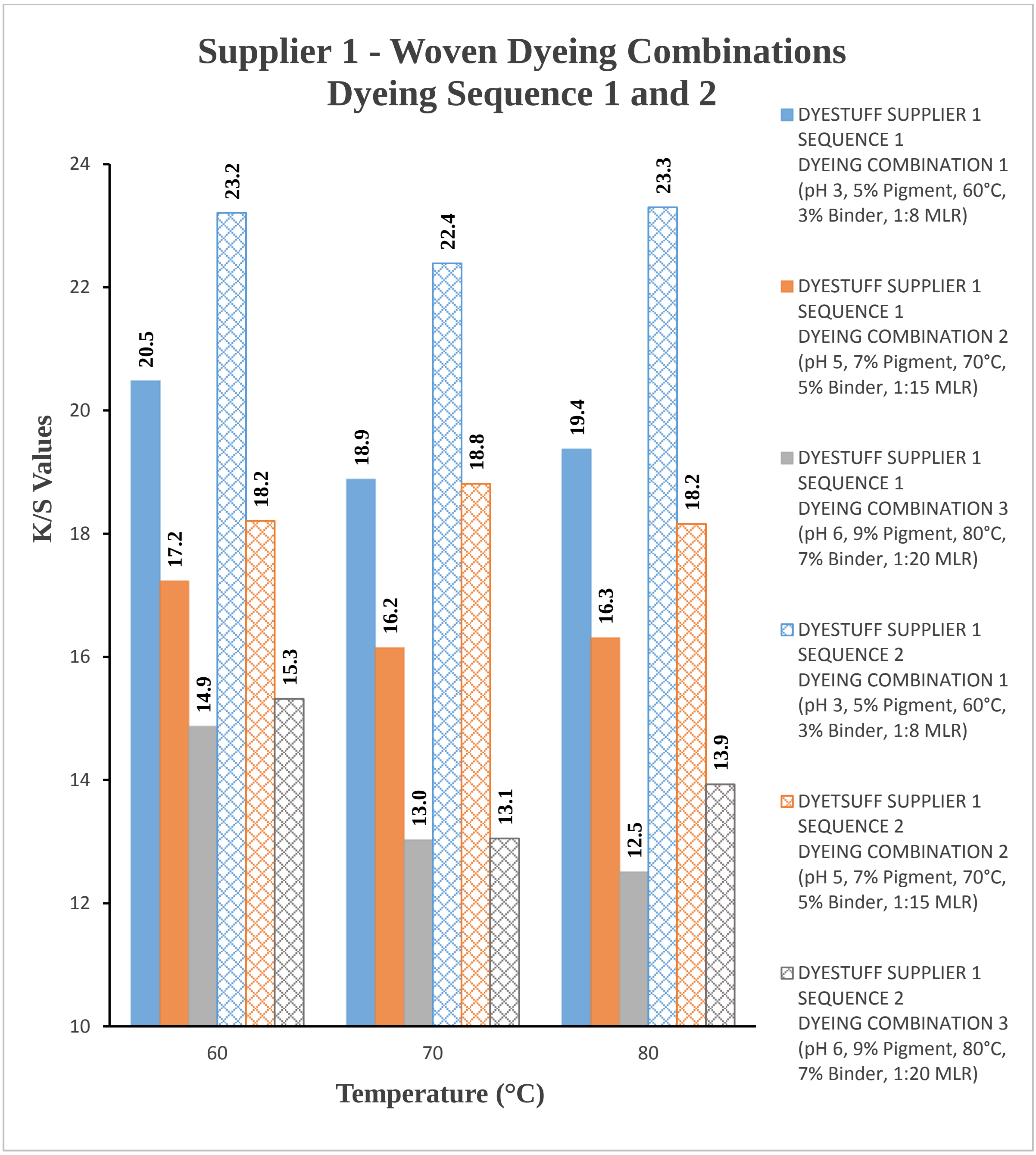


Figure 4.60 Effect of Temperature (°C) on K/S for the Dyeing Combinations for Woven Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

Table 4.60, shows that sequence 1 achieves acceptable pass ratings of 3/4 at all temperature levels for all dyeing combinations; while sequence 2 obtains the same at 70º and 80˚C for dyeing combination 1, and at 80˚C for dyeing combination 2. In addition, Figure 4.61 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, only sequence 1 achieves a pass at all temperature levels, however with corresponding K/S values lower than that for sequence 2.

Table 4.60 Woven Test Results for Temperature Levels Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
Temperature Trials:							WOVEN										Dyeing Combination Averages	Total Temperature Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	20.5	4/5	4/5	4/5	4/5	4/5	4	4/5	3/4	4	19.6	16.0
	4	3	5	70	3	1:8	18.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
	4	3	5	80	3	1:8	19.4	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
2	6	5	7	60	5	1:15	17.2	4/5	4/5	4/5	4	4/5	4	4	4	4	16.6	
	6	5	7	70	5	1:15	16.2	5	4/5	4/5	4/5	4/5	4/5	4/5	4	3/4		
	6	5	7	80	5	1:15	16.3	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
3	8	6	9	60	7	1:20	14.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4	13.5	
	8	6	9	70	7	1:20	13.0	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4		

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Temperature Trials:							WOVEN										Dyeing Combination Averages	Total Temperature Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	23.2	5	4/5	4/5	4/5	4/5	3	3	3	3	23.0	17.9
	4	3	5	70	3	1:8	22.4	5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3/4		
	4	3	5	80	3	1:8	23.3	5	4/5	4/5	4/5	4/5	4	4	4	3/4		
2	6	5	7	60	5	1:15	18.2	5	4/5	4/5	4/5	4/5	4	3/4	3	3	18.4	
	6	5	7	70	5	1:15	18.8	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3/4		
	6	5	7	80	5	1:15	18.2	5	4/5	4/5	4/5	4/5	4	3/4	4	3/4		
3	8	6	9	60	7	1:20	15.3	5	5	5	5	5	3/4	3	3	3	14.1	
	8	6	9	70	7	1:20	13.1	5	4/5	4/5	4/5	4/5	3	3	3	3		
	8	6	9	80	7	1:20	13.9	4/5	4/5	4/5	4/5	4/5	3/4	3	3	3		

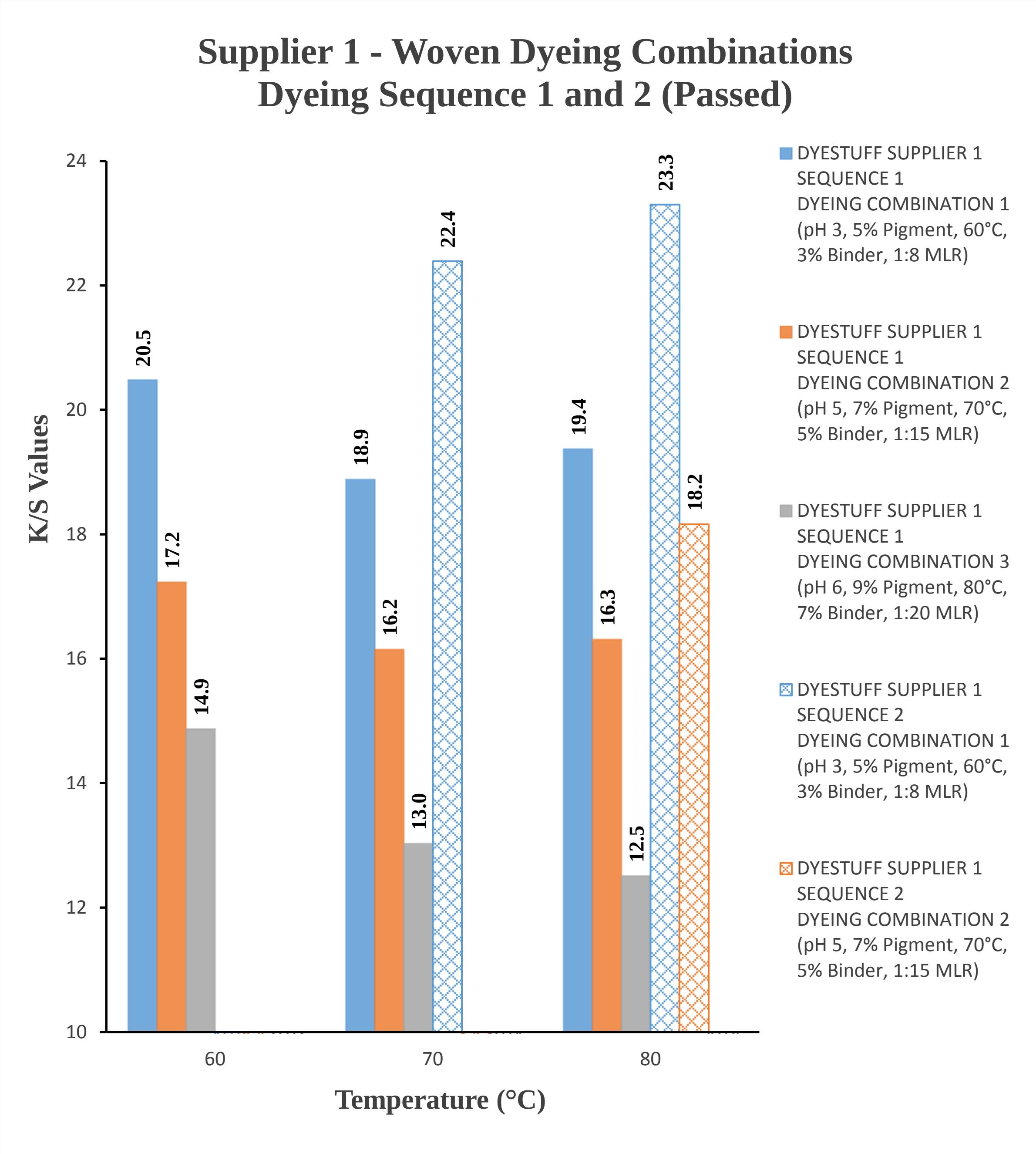


Figure 4.61 Grey Scale Ratings of 3/4 or Higher for Temperature Level Trials for Woven Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

4.3.4.6. DISCUSSION

Acceptable pass ratings of 3/4, as indicated in Figures 4.59 and 4.61, showed that only sequence 1 obtained pass ratings at all temperature levels for both the knitted and woven fabrics, with sequence 2 only achieving pass ratings at 70 ºC and 80ºC. In addition, 6 dyeing combinations for the knitted fabric, and 7 for the woven, achieved pass ratings of 4 or higher for all fastness, for sequence 1. Tables 4.61 and 4.62, represents the dyeing combinations that achieved a Grey

Scale rating of 4 or higher, with the ideal choice for knitted being K/S of 16.7 at 70°C, and that of woven being K/S of 19.4 at 80°C, both for dyeing combination 1, sequence 1, Supplier 1.

Table 4.61 Ideal Dyeing Combinations for Knitted Fabric for Temperature Level Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 1																		
Temperature Trials:							KNITTED											
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	70	3	1:8	16.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
2	6	5	7	60	5	1:15	15.1	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
	6	5	7	80	5	1:15	14.0	4/5	5	5	4/5	4/5	4	4	4	4		
3	8	6	9	60	7	1:20	12.6	4/5	5	5	4/5	4/5	4	4	4	4		
	8	6	9	70	7	1:20	11.5	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4		

Table 4.62 Ideal Dyeing Combinations for Woven Fabric for Temperature Level Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 1																
Temperature Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	70	3	1:8	18.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4
	4	3	5	80	3	1:8	19.4	4/5	4/5	4/5	4/5	4/5	4	4	4	4
2	6	5	7	60	5	1:15	17.2	4/5	4/5	4/5	4	4/5	4	4	4	4
	6	5	7	80	5	1:15	16.3	4/5	4/5	4/5	4/5	4/5	4	4	4	4
3	8	6	9	60	7	1:20	14.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4
	8	6	9	70	7	1:20	13.0	4/5	4/5	4/5	4/5	4/5	4	4	4	4
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4

4.3.4.7. SUPPLIER 2 (DYEING SEQUENCE 1 AND 2)

4.3.4.7.1. Knitted Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.62, with the highest K/S seen at 80°C for dyeing sequence 2. All dyeing combinations for sequence 1, show a decrease in K/S at 60°C; with the same observed at each temperature level for sequence 2, as the level of the remaining parameters are increased. The only visible trend is a decrease in K/S for dyeing combination 1 and 2, sequence 1, as the temperature is increased from 60° to 70º to 80°C, contrary to dyeing combination 1 and 2, sequence 2, which shows an increase in K/S as the temperature is increased from 60° to 70º to 80°C.

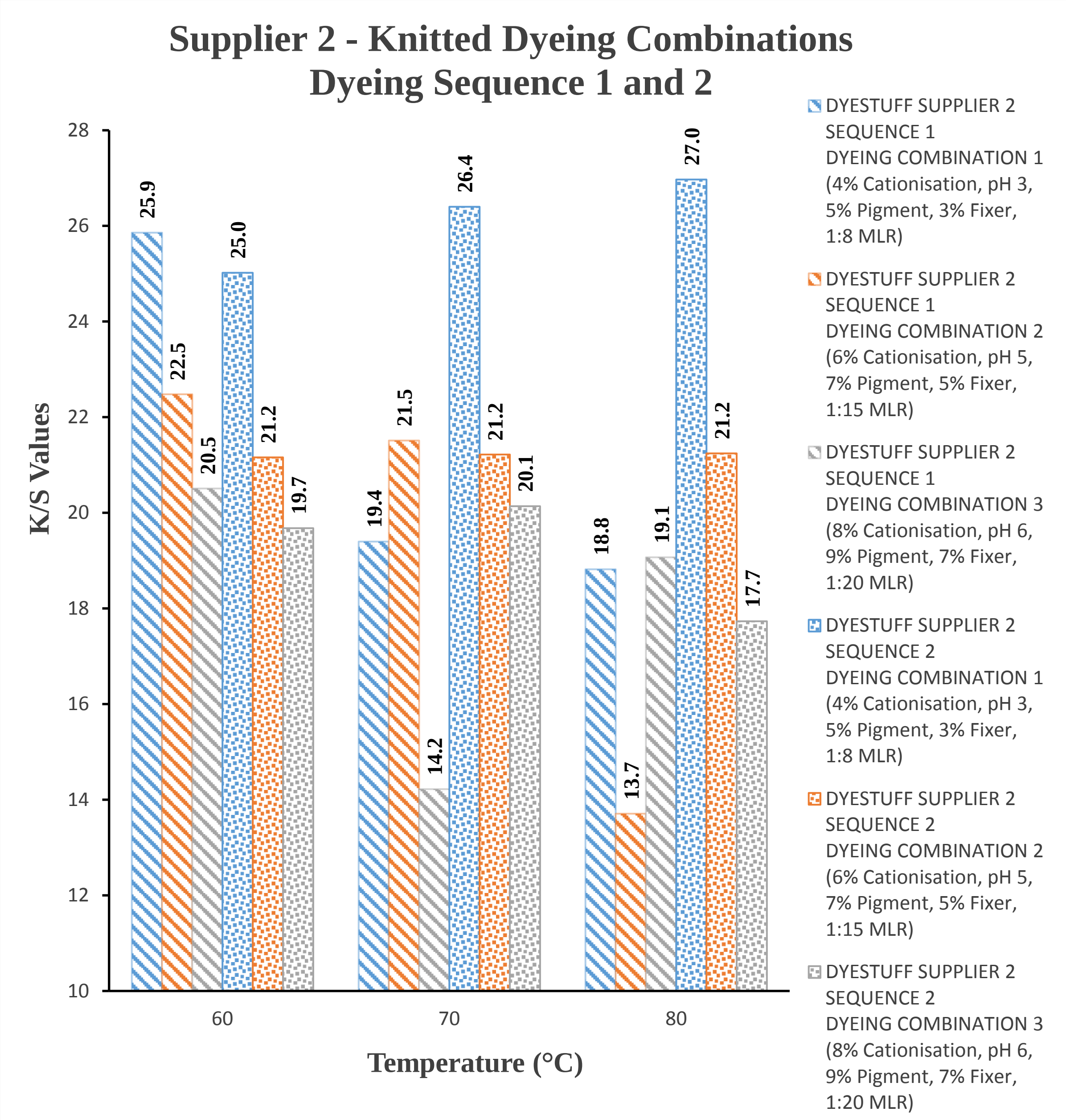


Figure 4.62 Effect of Temperature (°C) on K/S for the Dyeing Combinations for Knitted Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

Table 4.63, shows that sequence 1 achieves acceptable pass ratings at 60˚C for dyeing combinations 2 and 3, while sequence 2 obtains the same at 60˚C for dyeing combinations 1 and 3. In addition, Figure 4.63 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, sequence 1 and 2 obtains a pass at only 60˚C, however with a lower K/S than those achieved in the temperature trials.

Table 4.63 Knitted Test Results for Temperature Level Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
Temperature Trials:							KNITTED										Dyeing Combination Averages	Total Temperature Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.9	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3	24.7	17.9
	4	3	5	70	3	1:8	24.5	5	4/5	4	4	2	2	2	2/3	2/3		
	4	3	5	80	3	1:8	23.8	5	4	4	4	4	2/3	2	2	2		
2	6	5	7	60	5	1:15	15.4	5	5	5	5	5	4/5	4/5	4/5	4/5	17.1	
	6	5	7	70	5	1:15	21.5	5	4/5	5	5	4/5	3/4	3	3	3		
	6	5	7	80	5	1:15	14.3	5	4/5	4/5	4/5	4/5	2/3	2/3	2/3	2/3		
3	8	6	9	60	7	1:20	12.9	5	5	5	5	5	4	5	4	4	14.6	
	8	6	9	70	7	1:20	11.8	5	4/5	4/5	5	4/5	2/3	1/2	2	2/3		
	8	6	9	80	7	1:20	19.1	5	4/5	4/5	5	5	2/3	2/3	2/3	3		

SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Temperature Trials:							KNITTED										Dyeing Combination Averages	Total Temperature Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.0	5	4/5	5	5	5	3/4	4	4	4	24.1	21.1
	4	3	5	70	3	1:8	23.9	5	4/5	4/5	4/5	4/5	3	2/3	3	3		
	4	3	5	80	3	1:8	23.3	5	4/5	4/5	4/5	5	3	3	3/4	3		
2	6	5	7	60	5	1:15	22.7	5	5	5	5	5	4	3	3	3	21.4	
	6	5	7	70	5	1:15	21.2	5	4	4	4/5	4/5	2/3	2/3	2	3		
	6	5	7	80	5	1:15	20.2	4/5	4/5	5	5	4/5	3	3/4	4/5	4/5		
3	8	6	9	60	7	1:20	20.0	5	4/5	4/5	4/5	4/5	3/4	4	3/4	3/4	19.3	
	8	6	9	70	7	1:20	20.0	5	5	5	5	5	3	3	3/4	3/4		
	8	6	9	80	7	1:20	17.7	5	4/5	4/5	5	4/5	2/3	2	2	2/3		

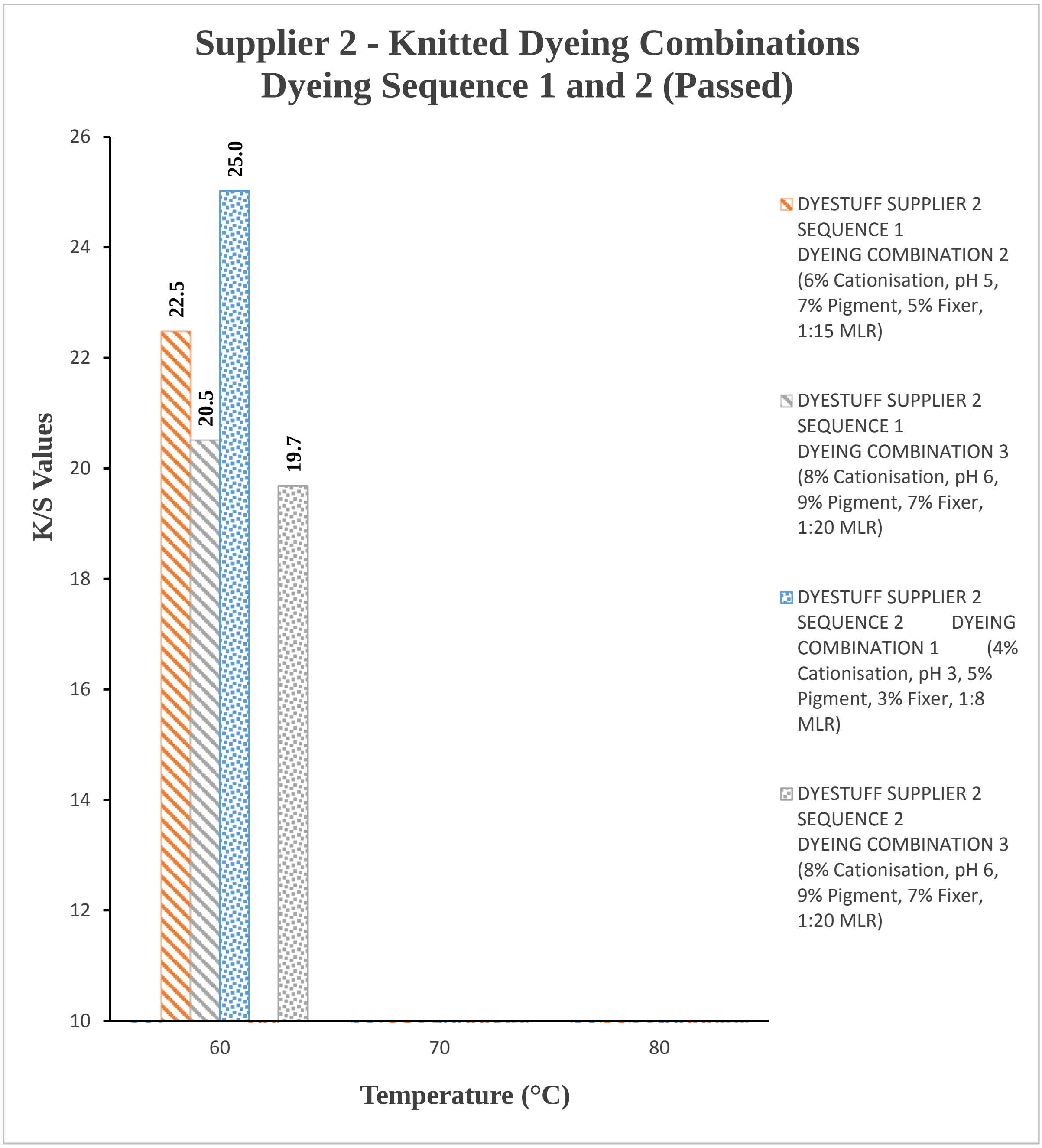


Figure 4.63 Grey Scale Ratings of 3/4 or Higher for Temperature Level Trials for Knitted Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

4.3.4.7.2. Woven Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.64, with the highest K/S seen at 70°C for dyeing sequence 2. All dyeing combinations for sequence 1 and 2, show a decrease in K/S at all temperature levels, as the level of the remaining parameters are increased. The only trend visible is a decrease in K/S for dyeing combination 2, sequence 2, as the temperature is increased from 60° to 70º to 80°C.

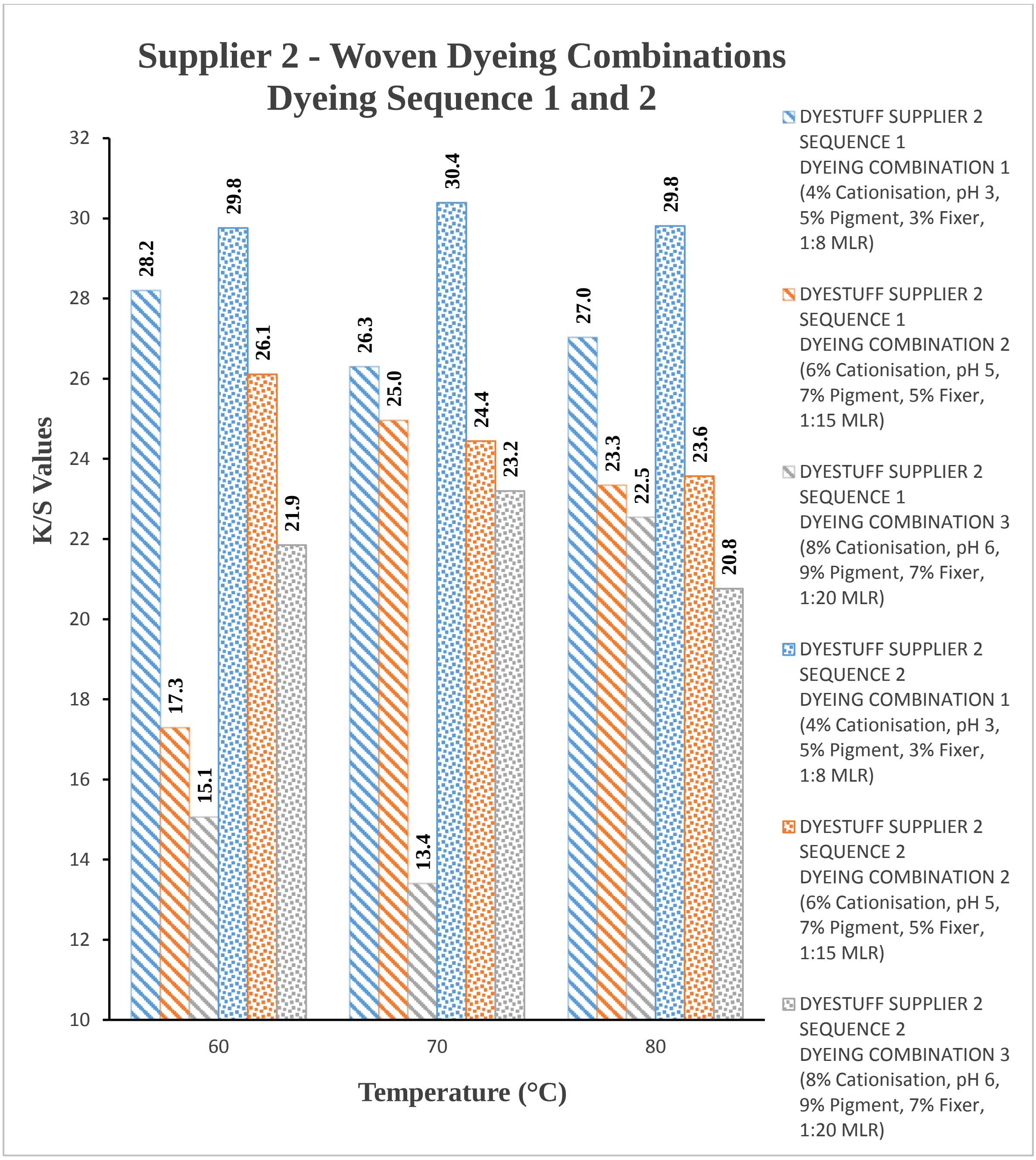


Figure 4.64 Effect of Temperature (°C) on K/S for the Dyeing Combinations for Woven Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

Table 4.64, shows that sequence 1 achieves acceptable pass ratings at 60˚C for dyeing combinations 2 and 3, while sequence 2 obtains the same at all temperature levels for dyeing combination 1, and at 60˚C for dyeing combinations 2 and 3. In addition, Figure 4.65 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, sequence 2 obtains a pass at all temperature levels, with higher K/S values than that for sequence 1.

Table 4.64 Woven Test Results for Temperature Levels Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
Temperature Trials:							WOVEN										Dyeing Combination Averages	Total Temperature Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	28.2	5	4/5	4/5	5	4/5	3	3	3	2/3	27.2	21.2
	4	3	5	70	3	1:8	26.3	5	4/5	4/5	4/5	4/5	4	2/3	2	2/3		
	4	3	5	80	3	1:8	27.0	5	4/5	4/5	4/5	4/5	4	3	2/3	2/3		
2	6	5	7	60	5	1:15	17.3	5	5	5	5	5	4/5	4/5	3/4	3/4	21.9	
	6	5	7	70	5	1:15	25.0	5	4/5	4/5	5	4/5	3	3	4	4		
	6	5	7	80	5	1:15	23.3	5	5	5	4/5	4/5	3	4	3	3		
3	8	6	9	60	7	1:20	15.1	5	5	5	5	5	4/5	4/5	3/4	4	17.0	
	8	6	9	70	7	1:20	13.4	5	5	4/5	4/5	4/5	3	3/4	3	3		
	8	6	9	80	7	1:20	22.5	5	5	5	5	4/5	3	3	3/4	3		

SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Temperature Trials:							WOVEN										Dyeing Combination Averages	Total Temperature Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	29.8	5	5	5	5	5	4	4	3/4	3/4	30.0	25.0
	4	3	5	70	3	1:8	30.4	5	5	5	5	5	4/5	4	3/4	4		
	4	3	5	80	3	1:8	29.8	5	5	5	5	5	4	4	3/4	3/4		
2	6	5	7	60	5	1:15	26.1	5	5	5	5	5	4/5	4	3/4	3/4	24.7	
	6	5	7	70	5	1:15	24.4	5	5	5	5	5	3/4	3	3	4		
	6	5	7	80	5	1:15	23.6	5	5	5	5	4	3/4	3	3	3/4		
3	8	6	9	60	7	1:20	21.9	5	5	5	4/5	5	4/5	4	4	4	21.9	
	8	6	9	70	7	1:20	23.2	5	5	5	5	5	3/4	3/4	4	3		
	8	6	9	80	7	1:20	20.8	5	5	5	5	5	3	3	3	2		

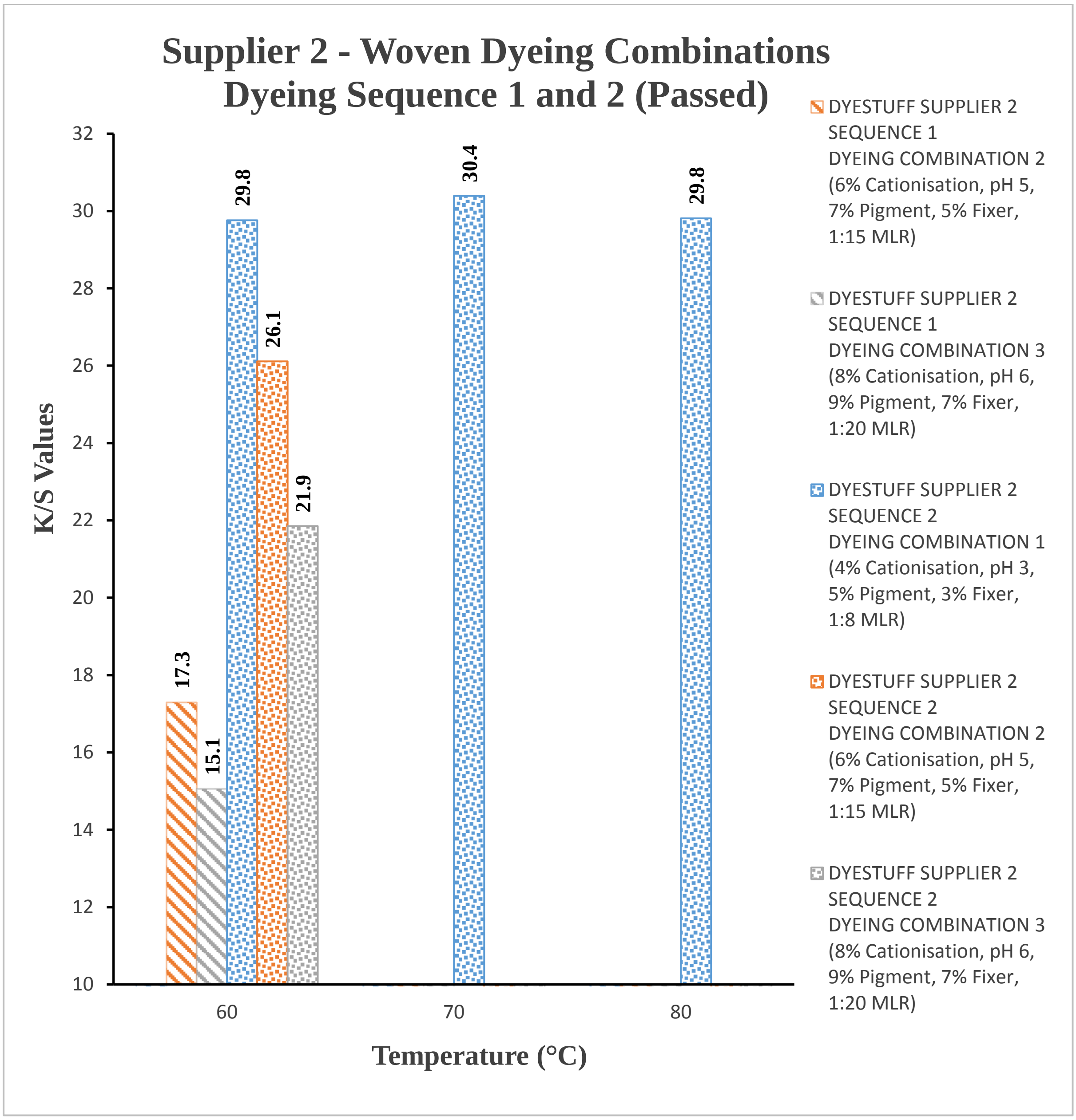


Figure 4.65 Grey Scale Ratings of 3/4 or Higher for Temperature Level Trials for Woven Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

4.3.4.8. DISCUSSION

Acceptable pass ratings of 3/4, as indicated in Figures 4.63 and 4.65, showed that sequence 1 achieved pass ratings for both fabrics at 60ºC, while sequence 2 obtained pass ratings at 60ºC for the knitted fabric, and at all temperature levels for the woven fabric. In addition, 2 dyeing combinations for the knitted fabric for sequence 1, and 1 dyeing combination for the woven fabric for sequence 2, achieved pass ratings of 4 or higher for all fastness. Tables 4.65 and 4.66, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for knitted being K/S of 15.4 at 60ºC for dyeing combination 2, for sequence 1, and that of woven being K/S of 21.9 at 60ºC for dyeing combination 3, for sequence 2.

Table 4.65 Ideal Dyeing Combinations for Knitted Fabric for Temperature Level Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 2																	
Temperature Trials:							KNITTED										
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub		
									Face	Back	Face	Back	Face	Back	Face	Back	
2	6	5	7	60	5	1:15	15.4	5	5	5	5	5	4/5	4/5	4/5	4/5	
3	8	6	9	60	7	1:20	12.9	5	5	5	5	5	4	5	4	4	

Table 4.66 Ideal Dyeing Combination for Woven Fabric for Temperature Level Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 2 - SUPPLIER 2																
Temperature Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
3	8	6	9	60	7	1:20	21.9	5	5	5	4/5	5	4/5	4	4	4

4.3.4.9. CONCLUSION

To conclude the results for all cationisation concentration trials for each supplier and sequence, the average K/S was taken into account. The effect of temperature on K/S, for both knitted and woven fabrics, for both suppliers and sequences showed a decrease in K/S as the temperature level increased from 60° to 70° to 80°C for all dyeing combinations, while the remaining 5 parameters (cationisation, pH, pigment, binder/fixer and MLR) increased in their respective levels.

The knitted and woven fabric for both suppliers achieved a higher average K/S for dyeing sequence 2 compared to that for dyeing sequence 1. Furthermore, both dyeing sequences for Supplier 2, achieved higher average K/S values compared to that for Supplier 1, for both fabrics. In addition, the K/S values for all woven fabric were higher compared to that for the knitted fabric, with the reasons for this difference being explained in section 4.3.7.

Taking the K/S values into account, it can be concluded that the ideal temperature for the knitted fabric was 70°C (K/S of 16.7), for sequence 1 for Supplier 1, while that for the woven fabric was 60°C (K/S of 21.9), for sequence 2 for Supplier 2. In addition, these K/S values also achieved Grey Scale ratings of 4 or higher for all fastness criteria. These ideal temperature levels are also supported by previous work carried out by Patra *et al* (2006), which reported that 60°C for the Blue pigment produced the best uptake, as well as Wu and Zhang (2013), who conducted pigment dyeing of Cotton/Polyester fabrics, and concluded that K/S increased with an increase in temperature from 50° to 70°C, after which it decreased with further increase in temperature, above 70°C.

4.3.5. Effect of Binder/Fixer Concentration

The two dyestuff suppliers were compared with one another to determine the effect of the binder/fixer concentrations on the outcome of K/S and fastness, when the binder/fixer concentrations were increased from 3 to 5 to 7% while the other 5 parameters (cationisation, pH, pigment, temperature and MLR) were kept constant, per dyeing combination. The binder/fixer concentration trials consisted of three dyeing combinations, with 3 trials per dyeing combination, and were performed using dyeing sequences 1 and 2. The results from these trials for both suppliers were compared with one another, first in terms of dyeing sequence 1, followed by dyeing sequence 2, and will be concluded in section 4.3.7. The dyeing combinations used in the trials for binder/fixer are presented in Table 4.67, with the results presented graphically.

Table 4.67 Dyeing Combinations for Binder/Fixer Concentration Trials.

	Binder/Fixer Concentration Trials						
	Cationisation (%)	**pH**	**Pigment (%)**	**Temp (°C)**	**Binder/ Fixer (%)**	**MLR**	**Trial No.**
Combination 1	4	3	5	60	3	1:8	1
	4	3	5	60	5	1:8	4
	4	3	5	60	7	1:8	7
Combination 2	6	5	7	70	3	1:15	2
	6	5	7	70	5	1:15	5
	6	5	7	70	7	1:15	8
Combination 3	8	6	9	80	3	1:20	3
	8	6	9	80	5	1:20	6
	8	6	9	80	7	1:20	9

4.3.5.1. SUPPLIERS 1 AND 2 (DYEING SEQUENCE 1)

4.3.5.1.1. Knitted Fabric Results

The K/S for both suppliers is represented in Figure 4.66, which shows that the K/S for Supplier 2 is higher than that for Supplier 1; with the greatest K/S at 7% Fixer. Supplier 1, shows a decrease in K/S at each level of binder, as the levels of the remaining parameters are increased, while Supplier 2 exhibits the same trend at 3 and 5% fixer. Furthermore, Supplier 1 shows a decrease in K/S, for all dyeing combinations, as the binder level increases from 3 to 5%.

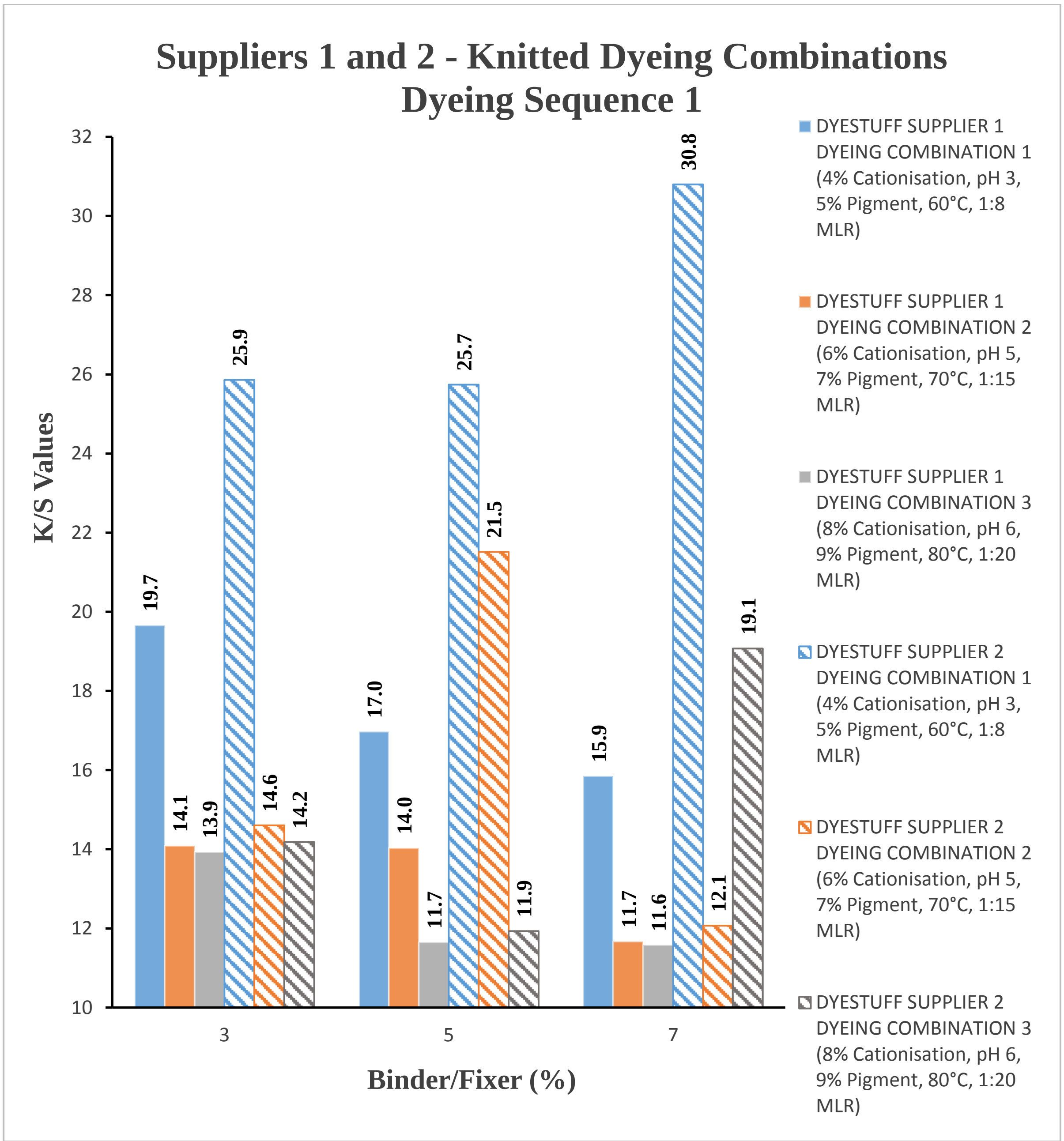


Figure 4.66 Effect of Binder/Fixer (%) on K/S for the Dyeing Combinations for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

Table 4.68, shows that Supplier 1 achieves acceptable pass ratings of 3/4 at 5 and 7% binder for all dyeing combinations, however, Supplier 2 achieves the same at 7% binder for dyeing combination 1. In addition, Figure 4.67 shows the dyeing combinations that have passed on all fastness with a rating of 3/4. Accordingly, both suppliers passed in terms of the fastness criteria, however with Supplier 1 achieving low K/S values compared to that for Supplier 2.

Table 4.68 Knitted Test Results for Binder/Fixer Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
Binder Trials:							KNITTED										Dyeing Combination Averages	Total Binder Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	19.7	4/5	3/4	4/5	3	3/4	2/3	2/3	2	2/3	17.5	
	4	3	5	60	5	1:8	17.0	4/5	4/5	4/5	4/5	4/5	4	4	3/4	4		
	4	3	5	60	7	1:8	15.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
2	6	5	7	70	3	1:15	14.1	4/5	4/5	4/5	4/5	4/5	3/4	3	3	3	13.3	
	6	5	7	70	5	1:15	14.0	5	4/5	4/5	4/5	4/5	4	3/4	4	4		13.7
	6	5	7	70	7	1:15	11.7	4/5	5	5	5	5	4	4	4	4		
3	8	6	9	80	3	1:20	13.9	4/5	4/5	4/5	4/5	4/5	3	3	3	3	12.4	
	8	6	9	80	5	1:20	11.7	4/5	4/5	4/5	4/5	4/5	3/4	3/4	4	4		
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4		

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
Fixer Trials:							KNITTED										Dyeing Combination Averages	Total Fixer Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.9	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3	27.5	
	4	3	5	60	5	1:8	25.7	5	5	5	5	5	3	3/4	3/4	4		
	4	3	5	60	7	1:8	30.8	5	5	5	5	5	4	4	3/4	3/4		
2	6	5	7	70	3	1:15	14.6	5	4/5	4/5	5	4/5	4	3	3	3	16.1	
	6	5	7	70	5	1:15	21.5	5	4/5	5	5	4/5	3/4	3	3	3		18.7
	6	5	7	70	7	1:15	12.1	5	5	4/5	4/5	4/5	3	2/3	3	2/3		
3	8	6	9	80	3	1:20	14.2	5	4/5	4/5	4/5	4/5	3	2/3	3	3	15.1	
	8	6	9	80	5	1:20	11.9	5	5	5	5	5	4	3	2/3	3		
	8	6	9	80	7	1:20	19.1	5	4/5	4/5	5	5	2/3	2/3	2/3	3		

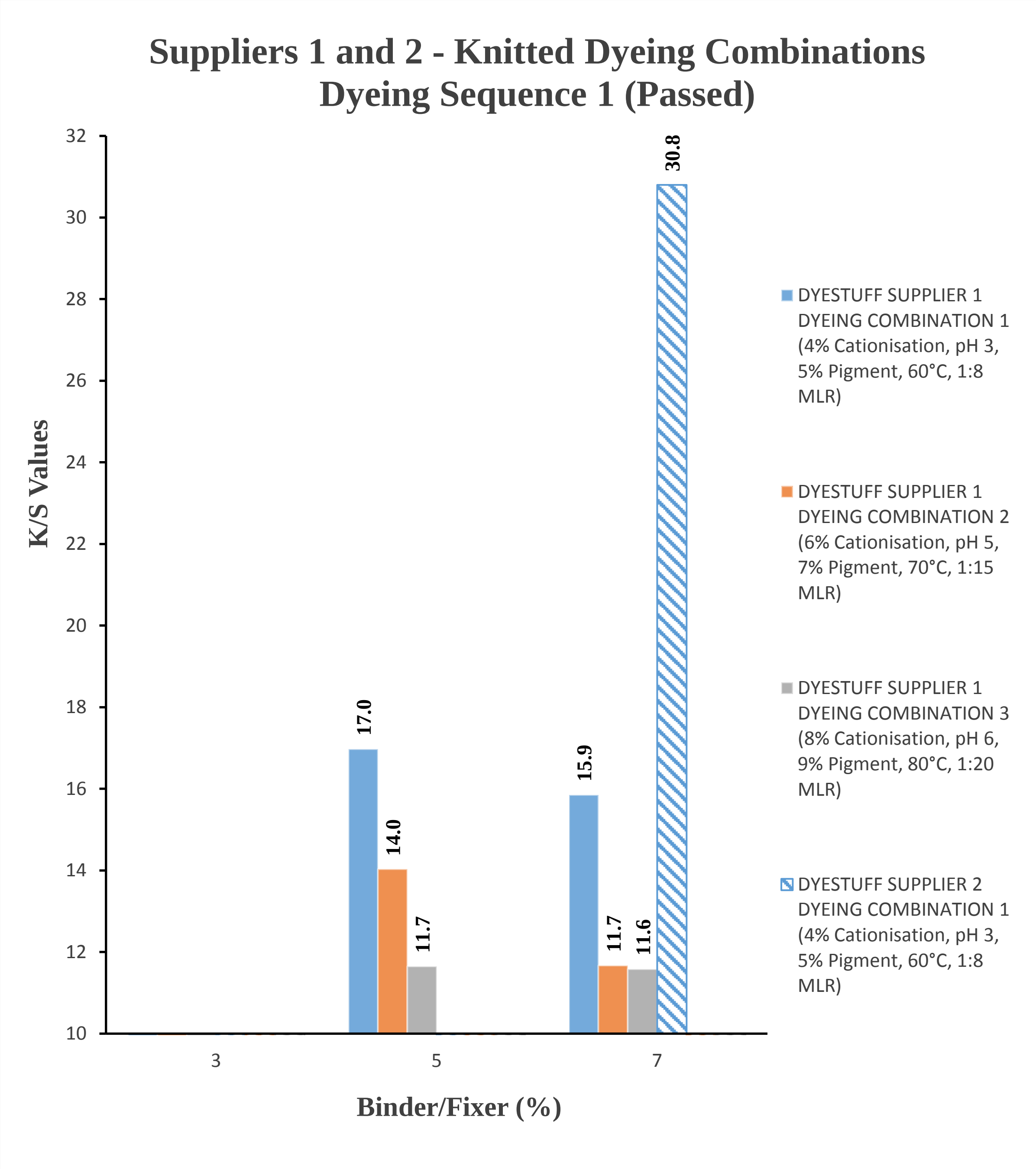


Figure 4.67 Grey Scale Ratings of 3/4 or Higher for Binder/Fixer Concentration Trials for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

4.3.5.1.2. Woven Fabric Results

The K/S for both suppliers is represented in Figure 4.68, which shows that the K/S, for Supplier 2 is higher than that for Supplier 1; with the greatest K/S at 7% Fixer. Supplier 1, shows a decrease in K/S at each level of binder, as the remaining parameters are increased, while Supplier 2 exhibits the same trend at 3 and 5% fixer. Furthermore, Supplier 1 shows a decrease in K/S, while Supplier 2 shows an increase in K/S, for dyeing combination 1, as the binder/fixer level increases from 3 to 5%.

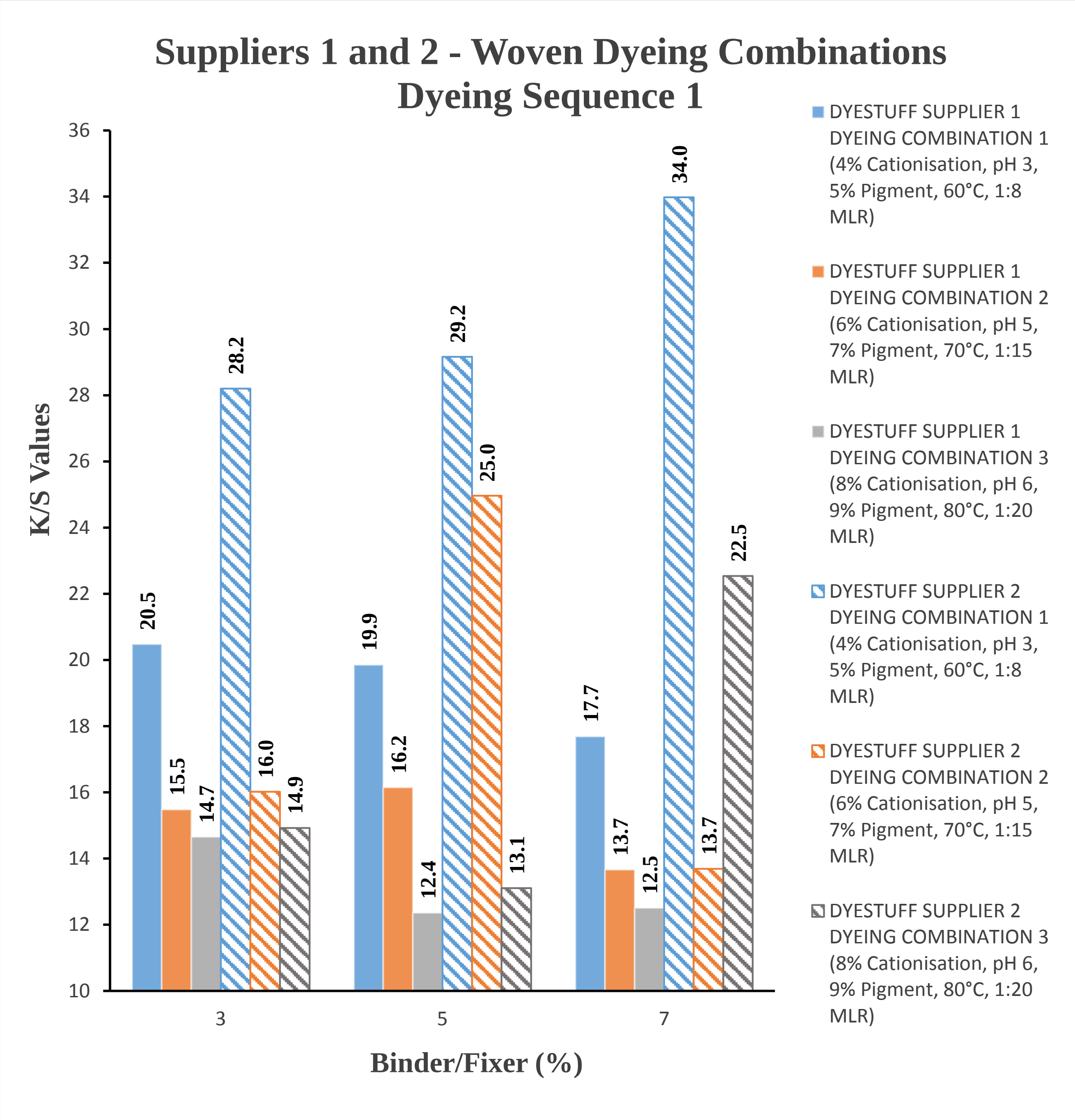


Figure 4.68 Effect of Binder/Fixer (%) on K/S for the Dyeing Combinations for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

Table 4.69, shows that Supplier 1 achieves acceptable pass ratings of 3/4 at all binder levels for all dyeing combinations, while Supplier 2, achieves acceptable pass ratings at 5 and 7% fixer for dyeing combination 1, and at 3% fixer for dyeing combination 3. In addition, Figure 4.69 shows the dyeing combinations that have passed on all fastness with a rating of 3/4. Accordingly, both suppliers passed in terms of all the fastness criteria, with Supplier 2 achieving much higher K/S values than that for Supplier 1.

Table 4.69 Woven Test Results for Binder/Fixer Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																				
Binder Trials:							WOVEN												Dyeing Combination Averages	Total Binder Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	20.5	4/5	4/5	4/5	4/5	4/5	4	4/5	3/4	4	19.3	15.3
	4	3	5	60	5	1:8	19.9	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4	4		
	4	3	5	60	7	1:8	17.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
2	6	5	7	70	3	1:15	15.5	4/5	4	4	4/5	4/5	3/4	3/4	3/4	3/4	15.1	
	6	5	7	70	5	1:15	16.2	5	4/5	4/5	4/5	4/5	4/5	4/5	4	3/4		
	6	5	7	70	7	1:15	13.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
3	8	6	9	80	3	1:20	14.7	4/5	4/5	4/5	4/5	4/5	4	4	3/4	4	13.2	
	8	6	9	80	5	1:20	12.4	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4		
SEQUENCE 1 - DYESTUFF SUPPLIER 2																				
Fixer Trials:							WOVEN												Dyeing Combination Averages	Total Fixer Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	28.2	5	4/5	4/5	5	4/5	3	3	3	2/3	30.4	21.0
	4	3	5	60	5	1:8	29.2	5	5	5	5	5	4	3/4	3/4	4		
	4	3	5	60	7	1:8	34.0	5	5	5	5	5	4	4	4	4		
2	6	5	7	70	3	1:15	16.0	4/5	5	5	5	5	3/4	4	3/4	3	18.2	
	6	5	7	70	5	1:15	25.0	5	4/5	4/5	5	4/5	3	3	4	4		
	6	5	7	70	7	1:15	13.7	5	4/5	5	5	5	3/4	3	2/3	2/3		
3	8	6	9	80	3	1:20	14.9	5	5	4/5	5	5	3/4	4	4	4	16.9	
	8	6	9	80	5	1:20	13.1	5	4/5	4/5	4/5	4/5	3	3/4	3	2/3		
	8	6	9	80	7	1:20	22.5	5	5	5	5	4/5	3	4	3/4	3		

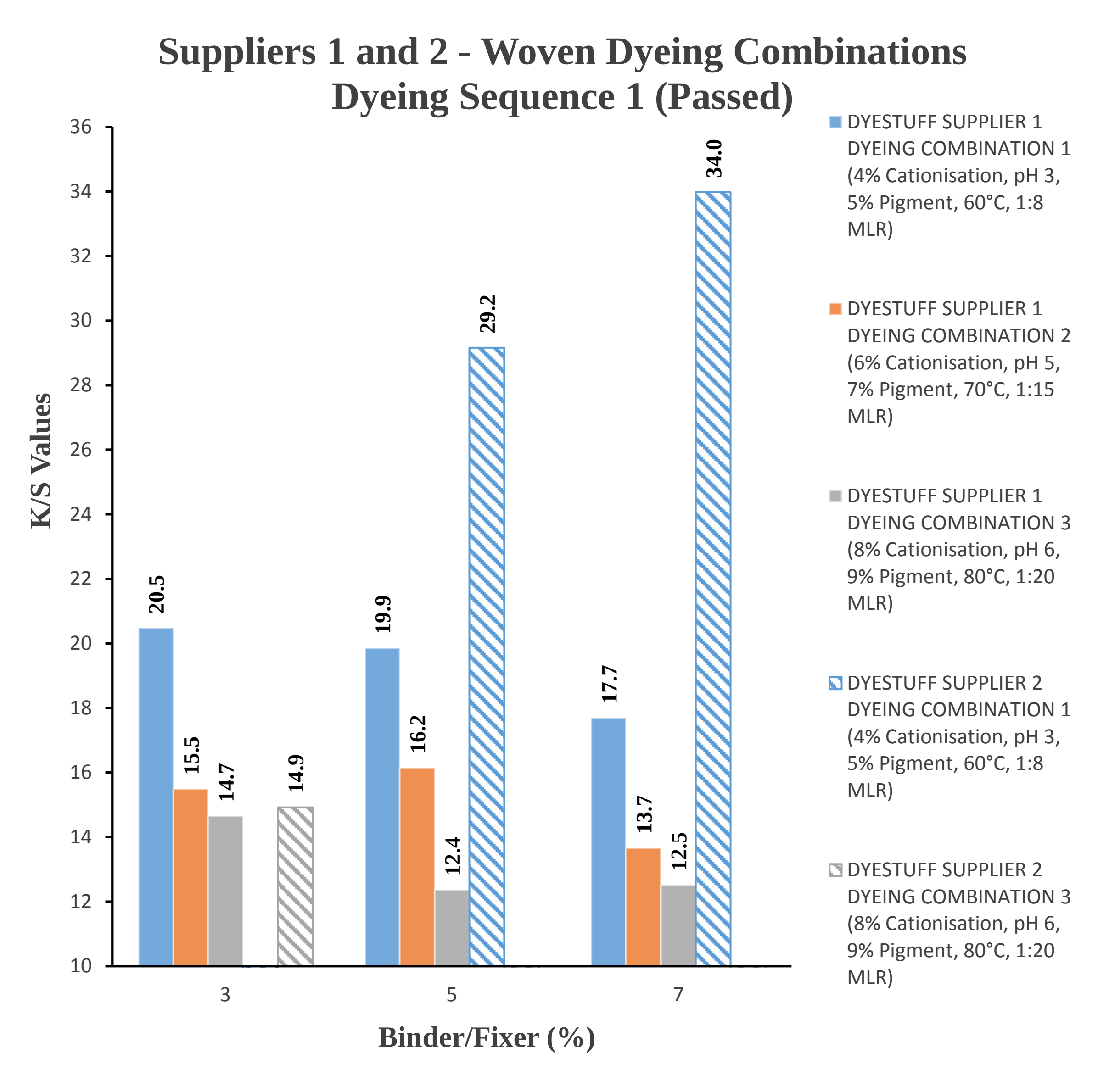


Figure 4.69 Grey Scale Ratings of 3/4 or Higher for Binder/Fixer Concentration Trials for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

4.3.5.2. <u>DISCUSSION</u>

Supplier 2 obtained a higher K/S for both fabrics, than that for Supplier 1, with acceptable pass ratings of 3/4, as indicated in Figures 4.67 and 4.69, which showed that for the knitted fabric, Supplier 1 obtained pass ratings at 5 and 7% binder, with Supplier 2 at 7%, while the woven fabric achieved passes for both suppliers at all binder/fixer concentrations. In addition, 3 dyeing combinations for the knitted, and 6 for the woven, achieved pass ratings of 4 or higher for all fastness criteria. Tables 4.70 and 4.71, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for the knitted fabric being K/S of 15.9 for

Supplier 1, and a far higher K/S of 34.0 for the woven fabric for Supplier 2, both at 7% binder/fixer for dyeing combination 1.

Table 4.70 Ideal Dyeing Combinations for Knitted Fabric for Binder/Fixer Concentration for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - SUPPLIER 1																
Binder Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	7	1:8	15.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4
2	6	5	7	70	7	1:15	11.7	4/5	5	5	5	5	4	4	4	4
3	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4

Table 4.71 Ideal Dyeing Combinations for Woven Fabric for Binder/Fixer Concentration for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - SUPPLIER 1																
Binder Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	5	1:8	19.9	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4	4
	4	3	5	60	7	1:8	17.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4
2	6	5	7	70	7	1:15	13.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4
3	8	6	9	80	5	1:20	12.4	4/5	4/5	4/5	4/5	4/5	4	4	4	4
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4
SEQUENCE 1 - SUPPLIER 2																
Fixer Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	7	1:8	34.0	5	5	5	5	5	4	4	4	4

4.3.5.3. SUPPLIERS 1 AND 2 (DYEING SEQUENCE 2)

4.3.5.3.1. Knitted Fabric Results

The K/S for both suppliers is represented in Figure 4.70, with the highest K/S at 7% Fixer. All dyeing combinations for Suppliers 1 and 2, show a decrease in K/S at each binder/fixer level, as the remaining parameters are increased. Supplier 1, for dyeing combination 1 and 3, show a decrease in K/S as the binder level increase from 3 to 5 to 7%, with the same trend observed for Supplier 2, for dyeing combination 3. Furthermore, Supplier 2, for dyeing combinations 1 and 2, shows an increase in K/S as the fixer level increases from 3 to 5 to 7%.

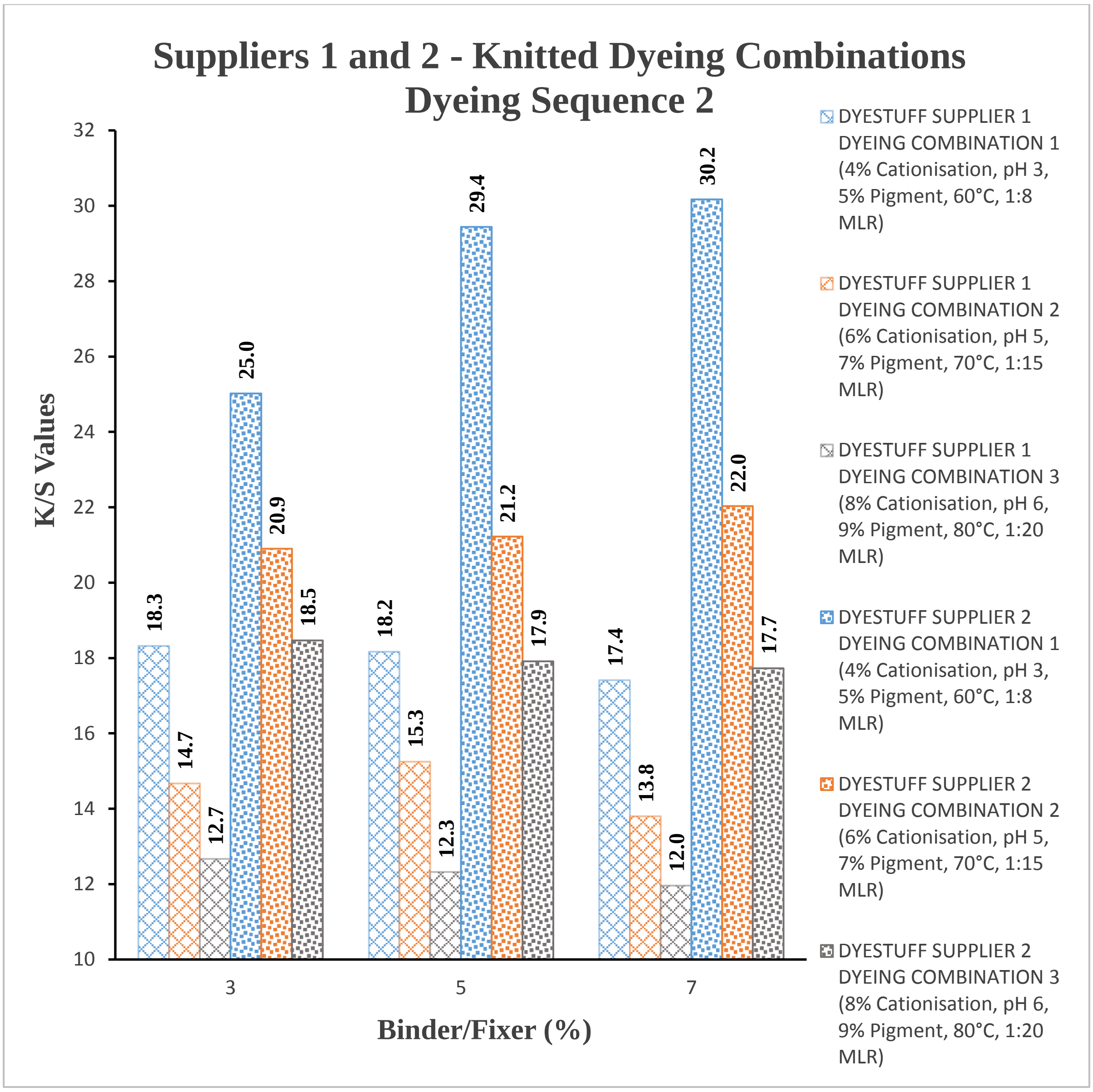


Figure 4.70 Effect of Binder/Fixer (%) on K/S for the Dyeing Combinations for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

Table 4.72, shows that Supplier 1 achieves an acceptable pass rating at 3% binder for dyeing combination 3; whereas Supplier 2 achieves acceptable pass ratings at 3 and 7% fixer for dyeing combination 1, and at 7% fixer for dyeing combination 2. In addition, Figure 4.71 shows the dyeing combinations that have passed in terms of all fastness with a rating of 3/4. Although both suppliers achieved a pass for the binder/fixer concentration trials, only Supplier 2 achieves high K/S values.

Table 4.72 Knitted Test Results for Binder/Fixer Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Binder Trials:							KNITTED										Dyeing Combination Averages	Total Binder Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	18.3	5	4	4	4	4	2/3	2/3	2/3	3	18.0	14.5
	4	3	5	60	5	1:8	18.2	4/5	4	4/5	4	4	3	3/4	3/4	3/4		
	4	3	5	60	7	1:8	17.4	5	4/5	4/5	4/5	4/5	3	3	3/4	3/4		
2	6	5	7	70	3	1:15	14.7	4/5	4	4	4	4	2/3	2/3	2/3	2/3	14.6	
	6	5	7	70	5	1:15	15.3	5	4/5	4/5	4/5	4/5	3/4	3	3	3		
	6	5	7	70	7	1:15	13.8	4/5	4/5	4/5	4/5	4/5	2	2	2	2		
3	8	6	9	80	3	1:20	12.7	4	4/5	4/5	4/5	4/5	4	3/4	3/4	3/4	12.3	
	8	6	9	80	5	1:20	12.3	4/5	4/5	4/5	4/5	4/5	2/3	2/3	2/3	2/3		
	8	6	9	80	7	1:20	12.0	5	4/5	4/5	4/5	4/5	2/3	2	2	3		

SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Fixer Trials:							KNITTED										Dyeing Combination Averages	Total Fixer Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.0	5	4/5	5	5	5	3/4	4	4	4	28.2	22.2
	4	3	5	60	5	1:8	29.4	5	4/5	5	5	5	4	4	4	3		
	4	3	5	60	7	1:8	30.2	5	4/5	4/5	4/5	4/5	4	4	3/4	4		
2	6	5	7	70	3	1:15	20.9	4/5	5	4/5	4/5	5	3	3	3/4	3	21.4	
	6	5	7	70	5	1:15	21.2	5	4	4	4/5	4/5	2/3	2/3	2	3		
	6	5	7	70	7	1:15	22.0	5	5	5	5	5	3/4	3/4	3/4	4		
3	8	6	9	80	3	1:20	18.5	5	4/5	4/5	4	4	3	2/3	3	2/3	18.0	
	8	6	9	80	5	1:20	17.9	5	4/5	4/5	4/5	4/5	4	3/4	2/3	3		
	8	6	9	80	7	1:20	17.7	5	4/5	4/5	5	4/5	2/3	2	2	2/3		

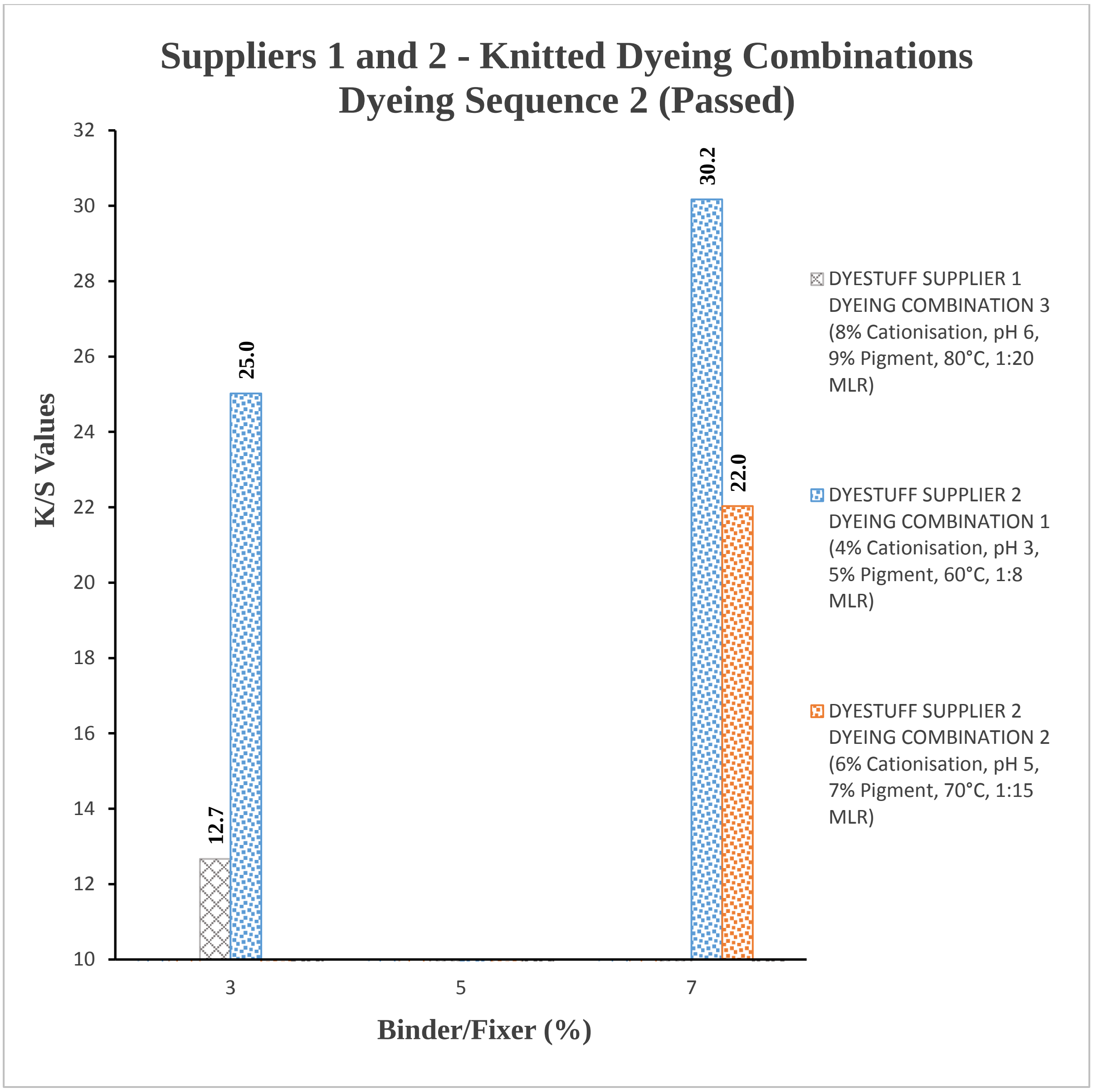


Figure 4.71 Grey Scale Ratings of 3/4 or Higher for Binder/Fixer Concentration Trials for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

4.3.5.3.2. <u>Woven Fabric Results</u>

The K/S for both suppliers is represented in Figure 4.72, with the highest K/S at 7% Fixer. All dyeing combinations for Suppliers 1 and 2, show a decrease in K/S at each binder/fixer concentration, as the remaining parameters are increased. Furthermore, Supplier 1, for dyeing combination 1 and 3, show a decrease in K/S as the binder level increase from 3 to 5 to 7%. Supplier 2, however, shows an increase in K/S, for dyeing combinations 1 and 2 as the fixer level increase from 3 to 5 to 7%.

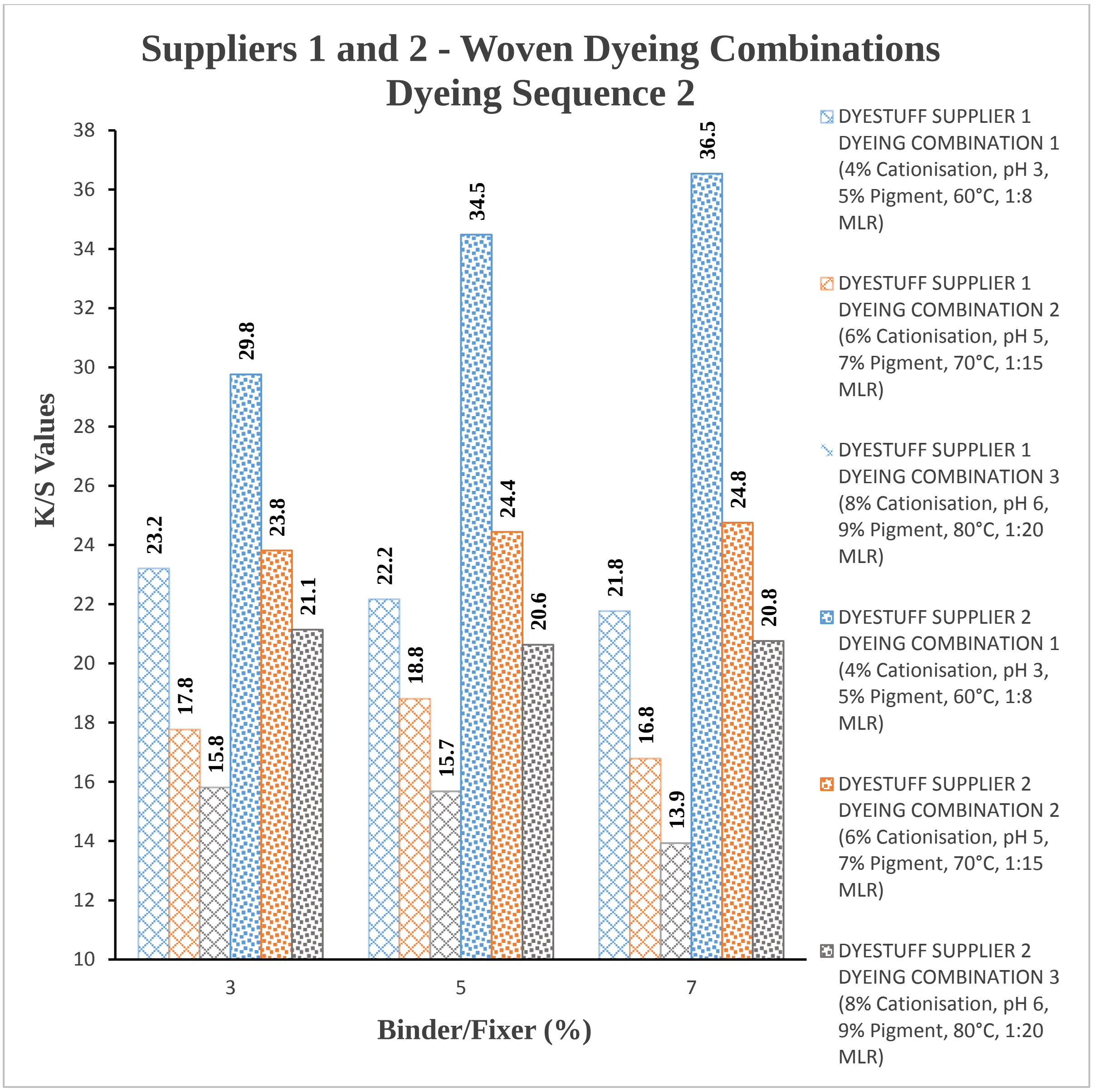


Figure 4.72 Effect of Binder/Fixer (%) on K/S for the Dyeing Combinations for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

Table 4.73, shows that Supplier 1 achieves an acceptable pass rating at 5% binder for dyeing combination 1; whereas Supplier 2 achieves the same at all fixer levels for dyeing combination 1, and at 7% fixer for dyeing combination 2. In addition, Figure 4.73 shows the dyeing combinations that have passed in terms of all fastness with a rating of 3/4. Although both suppliers achieved a pass for the binder/fixer concentration trials, only Supplier 2 achieves high K/S values.

Table 4.73 Woven Test Results for Binder/Fixer Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Binder Trials:							WOVEN										Dyeing Combination Averages	Total Binder Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	23.2	5	4/5	4/5	4/5	4/5	3	3	3	3	22.4	17.8
	4	3	5	60	5	1:8	22.2	4	4/5	4/5	4/5	4/5	4	4	4	3/4		
	4	3	5	60	7	1:8	21.8	5	4/5	4/5	4/5	4/5	3/4	3	3/4	3		
2	6	5	7	70	3	1:15	17.8	5	4/5	4/5	4/5	4/5	3	3	3	2/3	17.8	
	6	5	7	70	5	1:15	18.8	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3/4		
	6	5	7	70	7	1:15	16.8	4/5	4/5	4/5	4/5	4/5	2/3	2/3	2/3	2/3		
3	8	6	9	80	3	1:20	15.8	5	4/5	4/5	4/5	4/5	3/4	3	3	3	15.1	
	8	6	9	80	5	1:20	15.7	5	4/5	4/5	4/5	5	3	3	3	3		
	8	6	9	80	7	1:20	13.9	4/5	4/5	4/5	4/5	4/5	3/4	3	3	3		

SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Fixer Trials:							WOVEN										Dyeing Combination Averages	Total Fixer Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	29.8	5	5	5	5	5	4	4	3/4	3/4	33.6	25.8
	4	3	5	60	5	1:8	34.5	5	5	5	5	5	4/5	4	4	4		
	4	3	5	60	7	1:8	36.5	5	5	5	5	5	4/5	4/5	4/5	4		
2	6	5	7	70	3	1:15	23.8	5	5	5	5	5	3/4	3	2/3	3/4	24.3	
	6	5	7	70	5	1:15	24.4	5	5	5	5	5	3/4	3	3	4		
	6	5	7	70	7	1:15	24.8	5	5	5	5	5	3/4	4	4	4		
3	8	6	9	80	3	1:20	21.1	5	4/5	4/5	4/5	4/5	3	3	2/3	2/3	20.8	
	8	6	9	80	5	1:20	20.6	5	5	4/5	4/5	4/5	4	4	3	3		
	8	6	9	80	7	1:20	20.8	5	5	5	5	5	3	3	3	2		

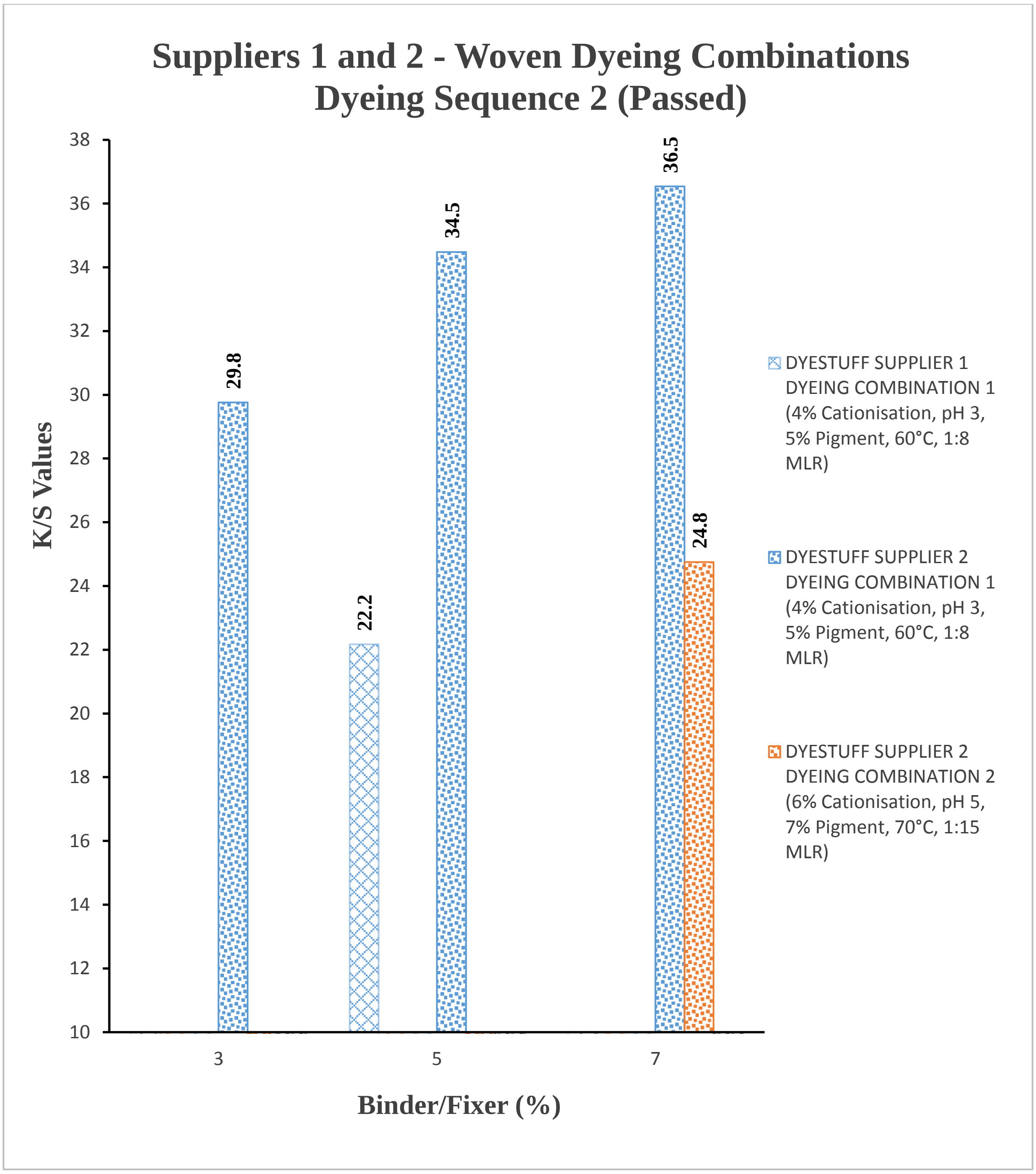


Figure 4.73 Grey Scale Ratings of 3/4 or Higher for Binder/Fixer Concentration Trials for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

4.3.5.4. DISCUSSION

Supplier 2 obtained a higher K/S for both fabrics, than that for Supplier 1, with acceptable pass ratings of 3/4, as indicated in Figures 4.71 and 4.73, which showed that Supplier 1 only obtained a pass rating at 3% binder for the knitted fabric and 5% binder for the woven fabric, whereas Supplier 2 obtained pass ratings at 3 and 7% fixer for the knitted fabric and at all fixer levels for the woven fabric. However, no dyeing combinations achieved pass ratings of 4 or higher for all fastness criteria, for the knitted fabric, whereas for the woven fabric, 2 dyeing combinations achieved pass ratings of 4 or higher for all fastness criteria, for Supplier 2. Table 4.74, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for the woven fabric being K/S of 36.5 at 7% fixer for dyeing combination 1, sequence 2, Supplier 2.

Table 4.74 Ideal Dyeing Combinations for Woven Fabric for Fixer Concentration Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - SUPPLIER 2																	
Fixer Trials:							WOVEN										
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub		
									Face	Back	Face	Back	Face	Back	Face	Back	
1	4	3	5	60	5	1:8	34.5	5	5	5	5	5	4/5	4	4	4	
	4	3	5	60	7	1:8	36.5	5	5	5	5	5	4/5	4/5	4/5	4	

4.3.5.5. <u>SUPPLIER 1 (DYEING SEQUENCE 1 AND 2)</u>

4.3.5.5.1. <u>Knitted Fabric Results</u>

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.74, with the highest K/S seen at 3% binder for dyeing sequence 1. All dyeing combinations for sequence 1 and 2, show a decrease in K/S at each binder level, as the level of the remaining parameters are increased. All dyeing combinations for sequence 1 and 2 show a decrease in K/S as the binder is increased from 3 to 5 to 7%, except for sequence 2, dyeing combination 2, which shows an increase in K/S from 3 to 5% followed by a decrease in K/S as the concentration level is increased from 5 to 7%.

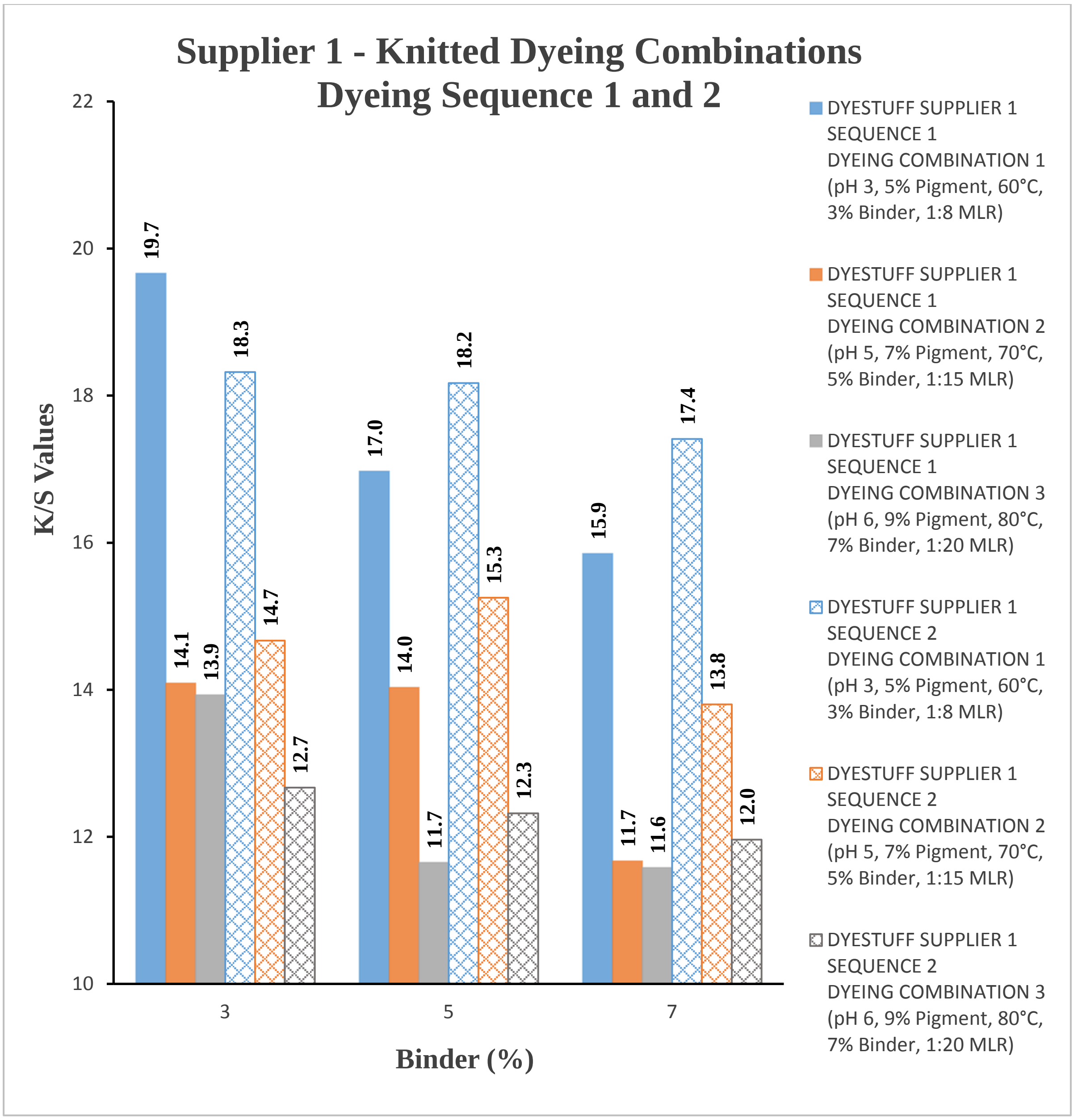


Figure 4.74 Effect of Binder (%) on K/S for the Dyeing Combinations for Knitted Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

Table 4.75, shows that sequence 1 achieves acceptable pass ratings at 5 and 7% binder for all dyeing combinations. Sequence 2, however achieves pass ratings at 3% binder for dyeing combination 3. In addition, Figure 4.75 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, sequence 1 obtains a pass at 5 and 7% binder, with K/S values lower than that for sequence 2.

Table 4.75 Knitted Test Results for Binder Concentration Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
Binder Trials:							KNITTED										Dyeing Combination Averages	Total Binder Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	19.7	4/5	3/4	4/5	3	3/4	2/3	2/3	2	2/3	17.5	13.7
	4	3	5	60	5	1:8	17.0	4/5	4/5	4/5	4/5	4/5	4	4	3/4	4		
	4	3	5	60	7	1:8	15.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
2	6	5	7	70	3	1:15	14.1	4/5	4/5	4/5	4/5	4/5	3/4	3	3	3	13.3	
	6	5	7	70	5	1:15	14.0	5	4/5	4/5	4/5	4/5	4	3/4	4	4		
	6	5	7	70	7	1:15	11.7	4/5	5	5	5	5	4	4	4	4		
3	8	6	9	80	3	1:20	13.9	4/5	4/5	4/5	4/5	4/5	3	3	3	3	12.4	
	8	6	9	80	5	1:20	11.7	4/5	4/5	4/5	4/5	4/5	3/4	3/4	4	4		
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4		
SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Binder Trials:							KNITTED										Dyeing Combination Averages	Total Binder Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	18.3	5	4	4	4	4	2/3	2/3	2/3	3	18.0	14.5
	4	3	5	60	5	1:8	18.2	4/5	4	4/5	4	4	3	3/4	3/4	3/4		
	4	3	5	60	7	1:8	17.4	5	4/5	4/5	4/5	4/5	3	3	3/4	3/4		
2	6	5	7	70	3	1:15	14.7	4/5	4	4	4	4	2/3	2/3	2/3	2/3	14.6	
	6	5	7	70	5	1:15	15.3	5	4/5	4/5	4/5	4/5	3/4	3	3	3		
	6	5	7	70	7	1:15	13.8	4/5	4/5	4/5	4/5	4/5	2	2	2	2		
3	8	6	9	80	3	1:20	12.7	4	4/5	4/5	4/5	4/5	4	3/4	3/4	3/4	12.3	
	8	6	9	80	5	1:20	12.3	4/5	4/5	4/5	4/5	4/5	2/3	2/3	2/3	2/3		
	8	6	9	80	7	1:20	12.0	5	4/5	4/5	4/5	4/5	2/3	2	2	3		

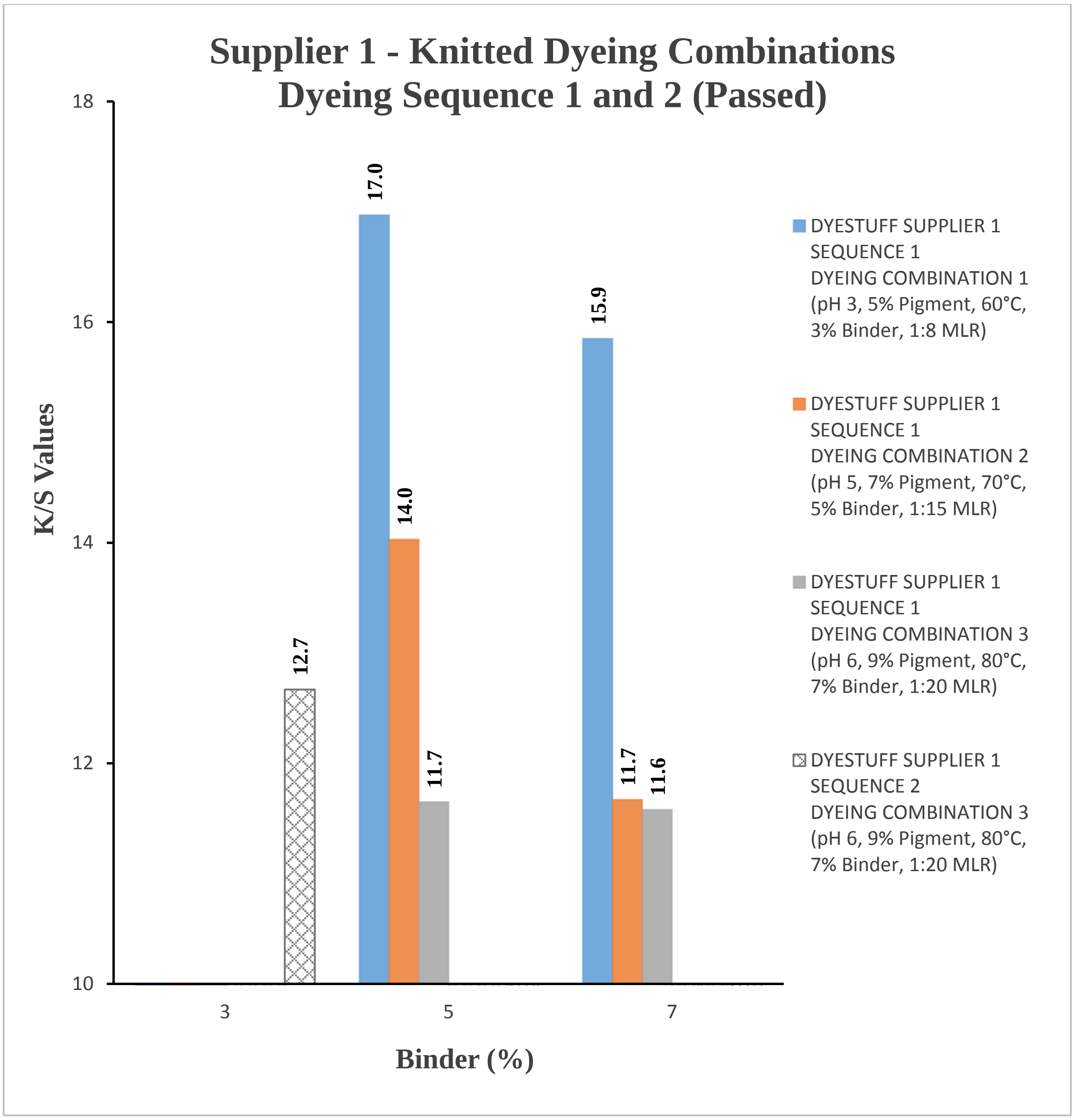


Figure 4.75 Grey Scale Ratings of 3/4 or Higher for Binder Concentration Trials for Knitted Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

4.3.5.5.2. Woven Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.76, with the highest K/S seen at 3% binder for dyeing sequence 2. All dyeing combinations for sequence 1 and 2, show a decrease in K/S at each binder level, as the level of the remaining parameters are increased. Sequence 1, dyeing combination 1, shows a decrease in K/S as the binder is increased from 3 to 5 to 7%, with the same observed for sequence 2, dyeing combinations 1 and 3.

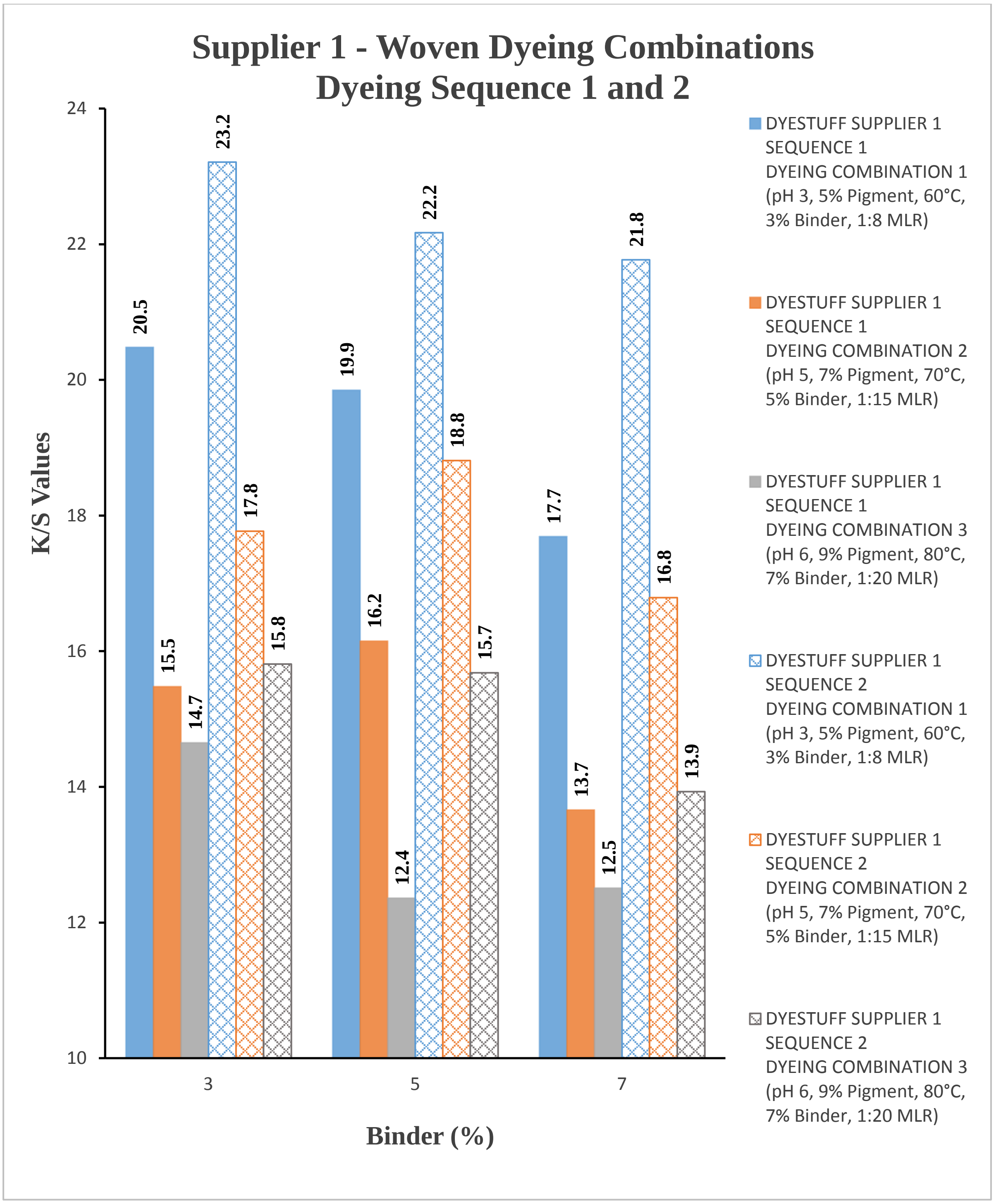


Figure 4.76 Effect of Binder (%) on K/S for the Dyeing Combinations for Woven Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

Table 4.76, shows that sequence 1 achieves acceptable pass ratings of 3/4 at all binder levels for all dyeing combinations, while sequence 2 obtains pass ratings at 5% binder for dyeing combination 1. In addition, Figure 4.77 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Although sequence 1 obtains a pass at all binder concentrations, the K/S values are much lower than that for sequence 2.

Table 4.76 Woven Test Results for Binder Concentration Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
Binder Trials:							WOVEN										Dyeing Combination Averages	Total Binder Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	20.5	4/5	4/5	4/5	4/5	4/5	4	4/5	3/4	4	19.3	15.3
	4	3	5	60	5	1:8	19.9	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4	4		
	4	3	5	60	7	1:8	17.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
2	6	5	7	70	3	1:15	15.5	4/5	4	4	4/5	4/5	3/4	3/4	3/4	3/4	15.1	
	6	5	7	70	5	1:15	16.2	5	4/5	4/5	4/5	4/5	4/5	4/5	4	3/4		
	6	5	7	70	7	1:15	13.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
3	8	6	9	80	3	1:20	14.7	4/5	4/5	4/5	4/5	4/5	4	4	3/4	4	13.2	
	8	6	9	80	5	1:20	12.4	4/5	4/5	4/5	4/5	4/5	4	4	4	4		
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4		
SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
Binder Trials:							WOVEN										Dyeing Combination Averages	Total Binder Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	23.2	5	4/5	4/5	4/5	4/5	3	3	3	3	22.4	17.8
	4	3	5	60	5	1:8	22.2	4	4/5	4/5	4/5	4/5	4	4	4	3/4		
	4	3	5	60	7	1:8	21.8	5	4/5	4/5	4/5	4/5	3/4	3	3/4	3		
2	6	5	7	70	3	1:15	17.8	5	4/5	4/5	4/5	4/5	3	3	3	2/3	17.8	
	6	5	7	70	5	1:15	18.8	5	4/5	4/5	4/5	4/5	3/4	3/4	3	3/4		
	6	5	7	70	7	1:15	16.8	4/5	4/5	4/5	4/5	4/5	2/3	2/3	2/3	2/3		
3	8	6	9	80	3	1:20	15.8	5	4/5	4/5	4/5	4/5	3/4	3	3	3	15.1	
	8	6	9	80	5	1:20	15.7	5	4/5	4/5	4/5	5	3	3	3	3		
	8	6	9	80	7	1:20	13.9	4/5	4/5	4/5	4/5	4/5	3/4	3	3	3		

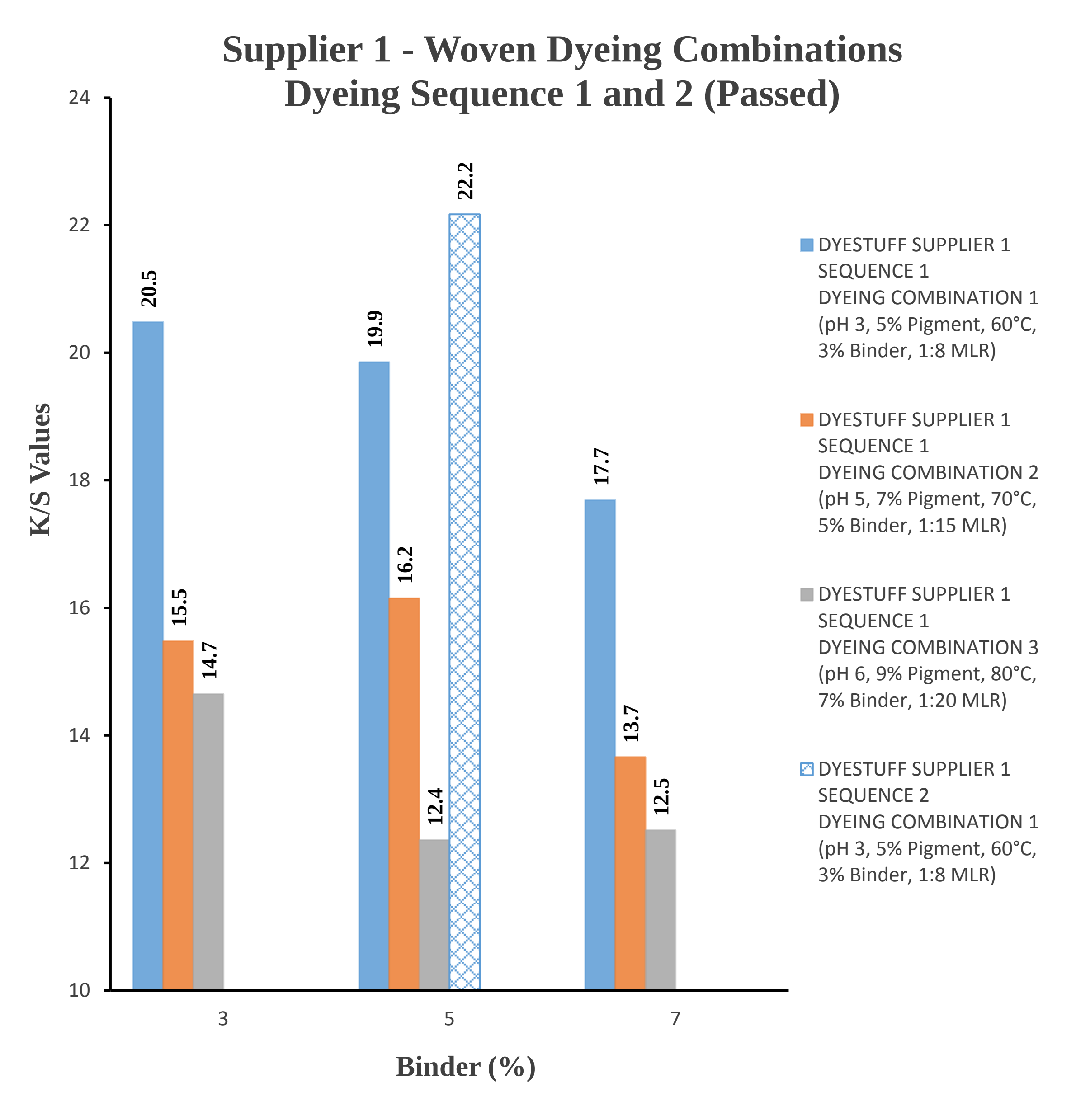


Figure 4.77 Grey Scale Ratings of 3/4 or Higher for Binder Concentration Trials for Woven Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

4.3.5.6. DISCUSSION

Acceptable pass ratings of 3/4, as indicated in Figures 4.75 and 4.77, showed that sequence 1 obtained pass ratings at 5 and 7% binder levels for the knitted fabric, and at all binder levels for the woven fabric, whereas sequence 2 only obtained a pass rating at 3% binder for the knitted fabric, and 5% binder for the woven fabric. In addition, 3 dyeing combinations for the knitted and 5 for the woven, achieved pass ratings of 4 or higher for all fastness, for sequence 1. Tables 4.77 and 4.78, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for knitted being K/S of 15.9 at 7% binder, and that of the woven being K/S of 19.9 at 5% binder, both for dyeing combination 1, sequence 1, Supplier 1.

Table 4.77 Ideal Dyeing Combinations for Knitted Fabric for Binder Concentration Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 1																
Binder Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	7	1:8	15.9	4/5	4/5	4/5	4/5	4/5	4	4	4	4
2	6	5	7	70	7	1:15	11.7	4/5	5	5	5	5	4	4	4	4
3	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4

Table 4.78 Ideal Dyeing Combinations for Woven Fabric for Binder Concentration Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 1																
Binder Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	5	1:8	19.9	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4	4
	4	3	5	60	7	1:8	17.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4
2	6	5	7	70	7	1:15	13.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4
3	8	6	9	80	5	1:20	12.4	4/5	4/5	4/5	4/5	4/5	4	4	4	4
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4

4.3.5.7. SUPPLIER 2 (DYEING SEQUENCE 1 AND 2)

4.3.5.7.1. Knitted Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.78, with the highest K/S seen at 7% fixer for dyeing sequence 1. All dyeing combinations for sequence 2, show a decrease in K/S at each fixer level, with sequence 1 showing the same at 3 and 5% fixer, as the level of the remaining parameters are increased. The only visible trend is for sequence 2, whereby dyeing combinations 1 and 2 show an increase in K/S, whereas dyeing combination 3 shows a decrease in K/S as the fixer is increased from 3 to 5 to 7%.

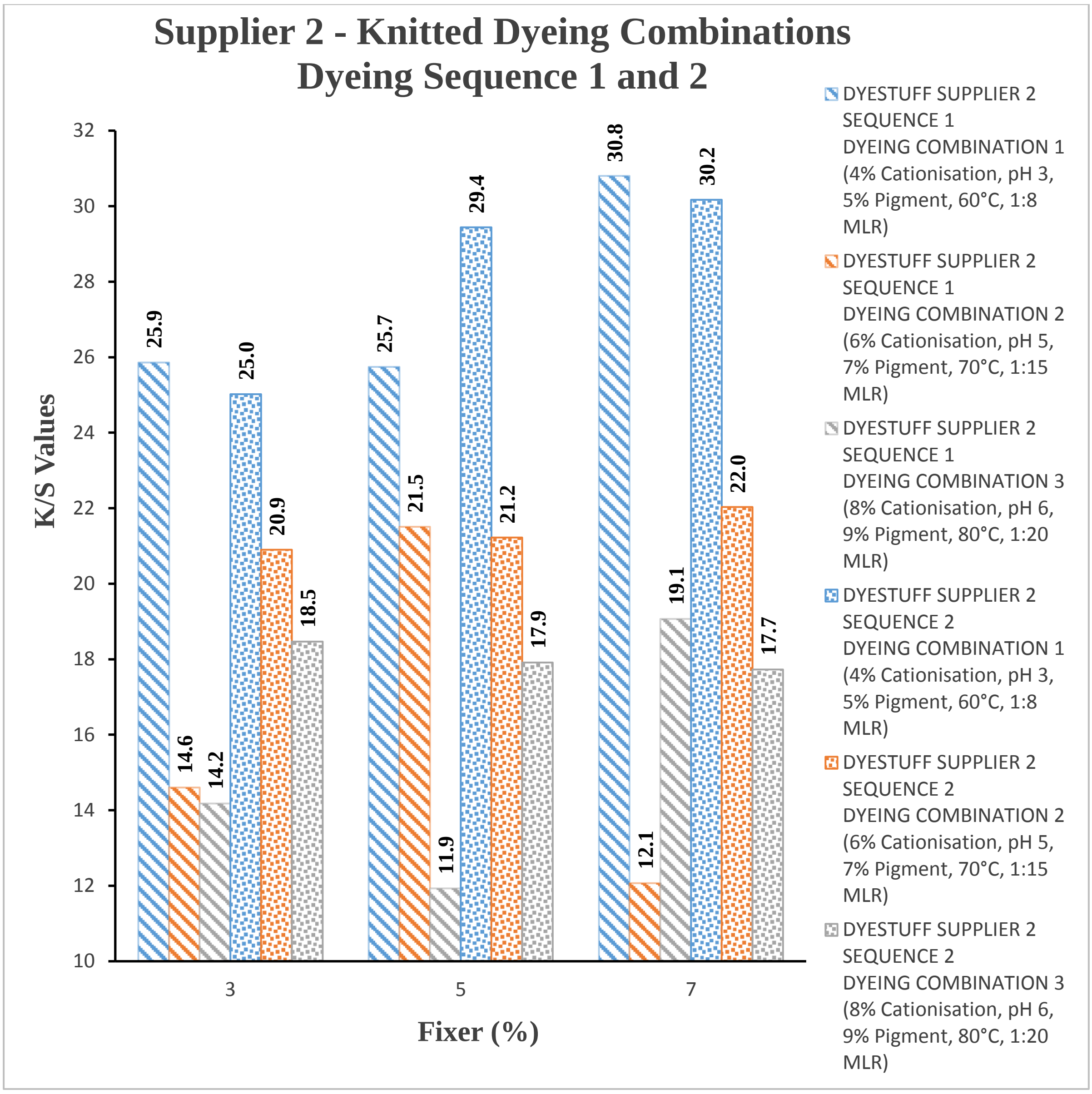


Figure 4.78 Effect of Fixer (%) on K/S for the Dyeing Combinations for Knitted Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

Table 4.79, shows that sequence 1 achieves an acceptable pass rating at 7% fixer for dyeing combination 1; while sequence 2 obtains the same at 3 and 7% fixer for dyeing combination 1, and at 7% fixer for dyeing combination 2. In addition, Figure 4.79 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, both sequences obtains a pass at 7% fixer, with a high K/S.

Table 4.79 Knitted Test Results for Fixer Concentration Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
Fixer Trials:							KNITTED										Dyeing Combination Averages	Total Fixer Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.9	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3	27.5	18.7
	4	3	5	60	5	1:8	25.7	5	5	5	5	5	3	3/4	3/4	4		
	4	3	5	60	7	1:8	30.8	5	5	5	5	5	4	4	3/4	3/4		
2	6	5	7	70	3	1:15	14.6	5	4/5	4/5	5	4/5	4	3	3	3	16.1	
	6	5	7	70	5	1:15	21.5	5	4/5	5	5	4/5	3/4	3	3	3		
	6	5	7	70	7	1:15	12.1	5	5	4/5	4/5	4/5	3	2/3	3	2/3		
3	8	6	9	80	3	1:20	14.2	5	4/5	4/5	4/5	4/5	3	2/3	3	3	15.1	
	8	6	9	80	5	1:20	11.9	5	5	5	5	5	4	3	2/3	3		
	8	6	9	80	7	1:20	19.1	5	4/5	4/5	5	5	2/3	2/3	2/3	3		
SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Fixer Trials:							KNITTED										Dyeing Combination Averages	Total Fixer Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.0	5	4/5	5	5	5	3/4	4	4	4	28.2	22.2
	4	3	5	60	5	1:8	29.4	5	4/5	5	5	5	4	4	4	3		
	4	3	5	60	7	1:8	30.2	5	4/5	4/5	4/5	4/5	4	4	3/4	4		
2	6	5	7	70	3	1:15	20.9	4/5	5	4/5	4/5	5	3	3	3/4	3	21.4	
	6	5	7	70	5	1:15	21.2	5	4	4	4/5	4/5	2/3	2/3	2	3		
	6	5	7	70	7	1:15	22.0	5	5	5	5	5	3/4	3/4	3/4	4		
3	8	6	9	80	3	1:20	18.5	5	4/5	4/5	4	4	3	2/3	3	2/3	18.0	
	8	6	9	80	5	1:20	17.9	5	4/5	4/5	4/5	4/5	4	3/4	2/3	3		
	8	6	9	80	7	1:20	17.7	5	4/5	4/5	5	4/5	2/3	2	2	2/3		

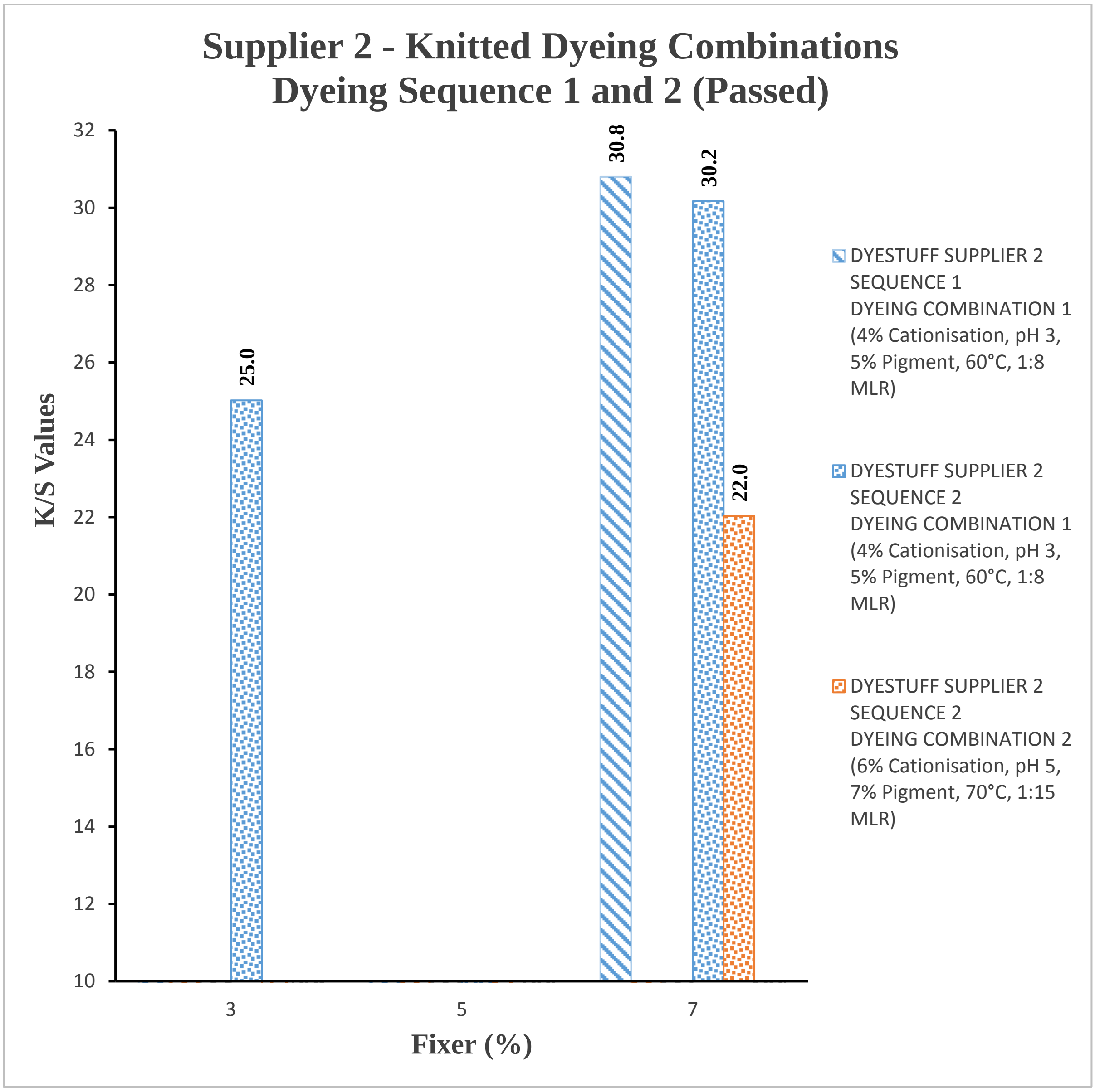


Figure 4.79 Grey Scale Ratings of 3/4 or Higher for Fixer Concentration Trials for Knitted Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

4.3.5.7.2. Woven Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.80, with the highest K/S seen at 7% fixer for dyeing sequence 2. All dyeing combinations for sequence 2, show a decrease in K/S at each fixer level, with sequence 1 showing the same at 3 and 5% fixer, as the level of the remaining parameters are increased. The visible trend is an increase in K/S for sequence 1, dyeing combination 1, and for sequence 2, dyeing combinations 1 and 2 as the fixer is increased from 3 to 5 to 7%.

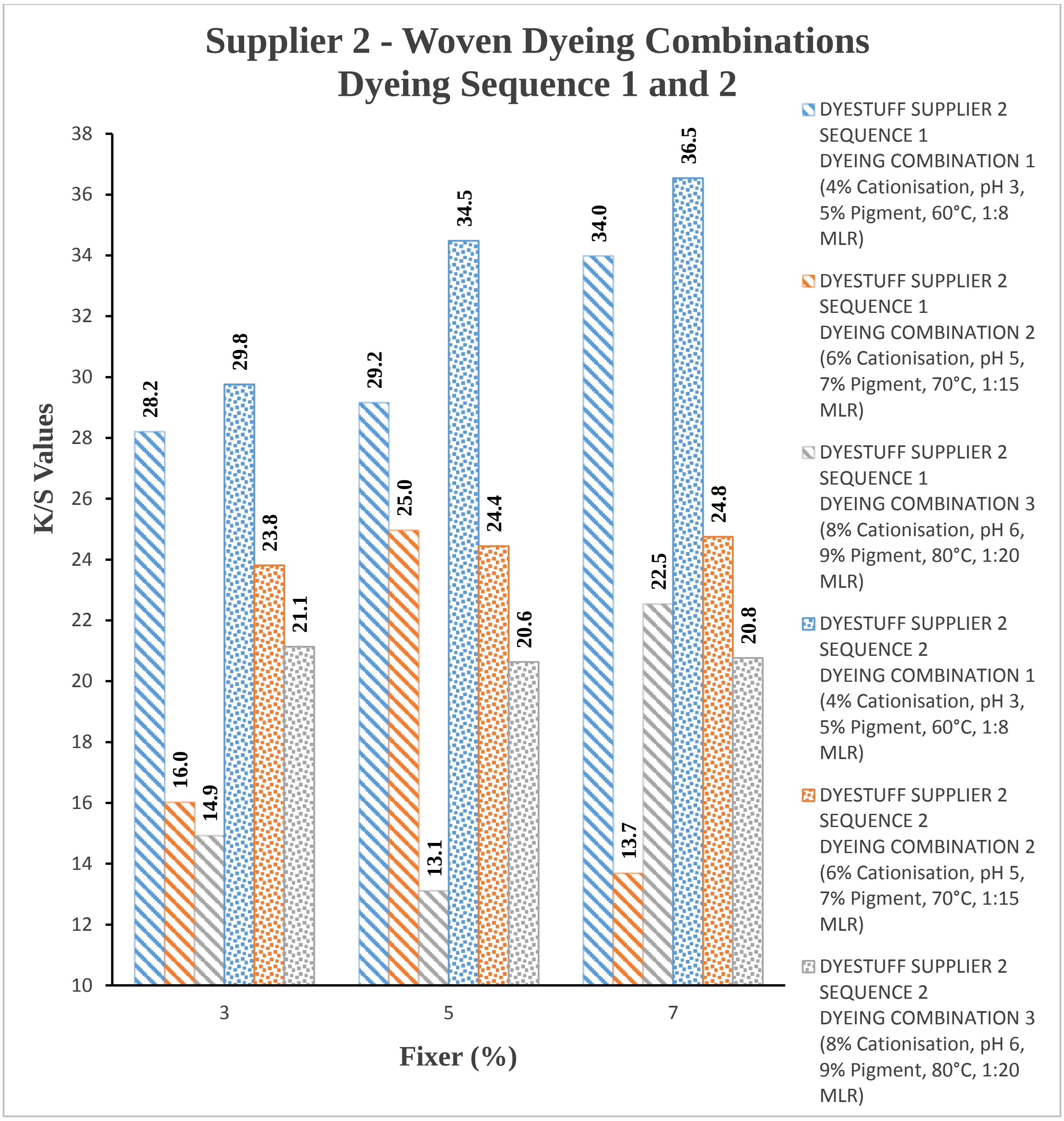


Figure 4.80 Effect of Fixer (%) on K/S for the Dyeing Combinations for Woven Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

Table 4.80, shows that sequence 1 achieves acceptable pass ratings of 3/4 at 5 and 7% fixer for dyeing combination 1 and at 3% fixer for dyeing combination 3; while sequence 2 obtains the same at all levels of fixer for dyeing combination 1, and at 7% fixer for dyeing combination 2. In addition, Figure 4.81 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, both sequences obtains a pass at all fixer concentrations, with K/S values being higher for sequence 2.

Table 4.80 Woven Test Results for Fixer Concentration Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
Fixer Trials:							WOVEN										Dyeing Combination Averages	Total Fixer Average
							K/S	Wash	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	(450nm)	Fastness	Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	28.2	5	4/5	4/5	5	4/5	3	3	3	2/3	30.4	21.0
	4	3	5	60	5	1:8	29.2	5	5	5	5	5	4	3/4	3/4	4		
	4	3	5	60	7	1:8	34.0	5	5	5	5	5	4	4	4	4		
2	6	5	7	70	3	1:15	16.0	4/5	5	5	5	5	3/4	4	3/4	3	18.2	
	6	5	7	70	5	1:15	25.0	5	4/5	4/5	5	4/5	3	3	4	4		
	6	5	7	70	7	1:15	13.7	5	4/5	5	5	5	3/4	3	2/3	2/3		
3	8	6	9	80	3	1:20	14.9	5	5	4/5	5	5	3/4	4	4	4	16.9	
	8	6	9	80	5	1:20	13.1	5	4/5	4/5	4/5	4/5	3	3/4	3	2/3		
	8	6	9	80	7	1:20	22.5	5	5	5	5	4/5	3	4	3/4	3		

SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
Fixer Trials:							WOVEN										Dyeing Combination Averages	Total Fixer Average
							K/S	Wash	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	(450nm)	Fastness	Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	29.8	5	5	5	5	5	4	4	3/4	3/4	33.6	25.8
	4	3	5	60	5	1:8	34.5	5	5	5	5	5	4/5	4	4	4		
	4	3	5	60	7	1:8	36.5	5	5	5	5	5	4/5	4/5	4/5	4		
2	6	5	7	70	3	1:15	23.8	5	5	5	5	5	3/4	3	2/3	3/4	24.3	
	6	5	7	70	5	1:15	24.4	5	5	5	5	5	3/4	3	3	4		
	6	5	7	70	7	1:15	24.8	5	5	5	5	5	3/4	4	4	4		
3	8	6	9	80	3	1:20	21.1	5	4/5	4/5	4/5	4/5	3	3	2/3	2/3	20.8	
	8	6	9	80	5	1:20	20.6	5	5	4/5	4/5	4/5	4	4	3	3		
	8	6	9	80	7	1:20	20.8	5	5	5	5	5	3	3	3	2		

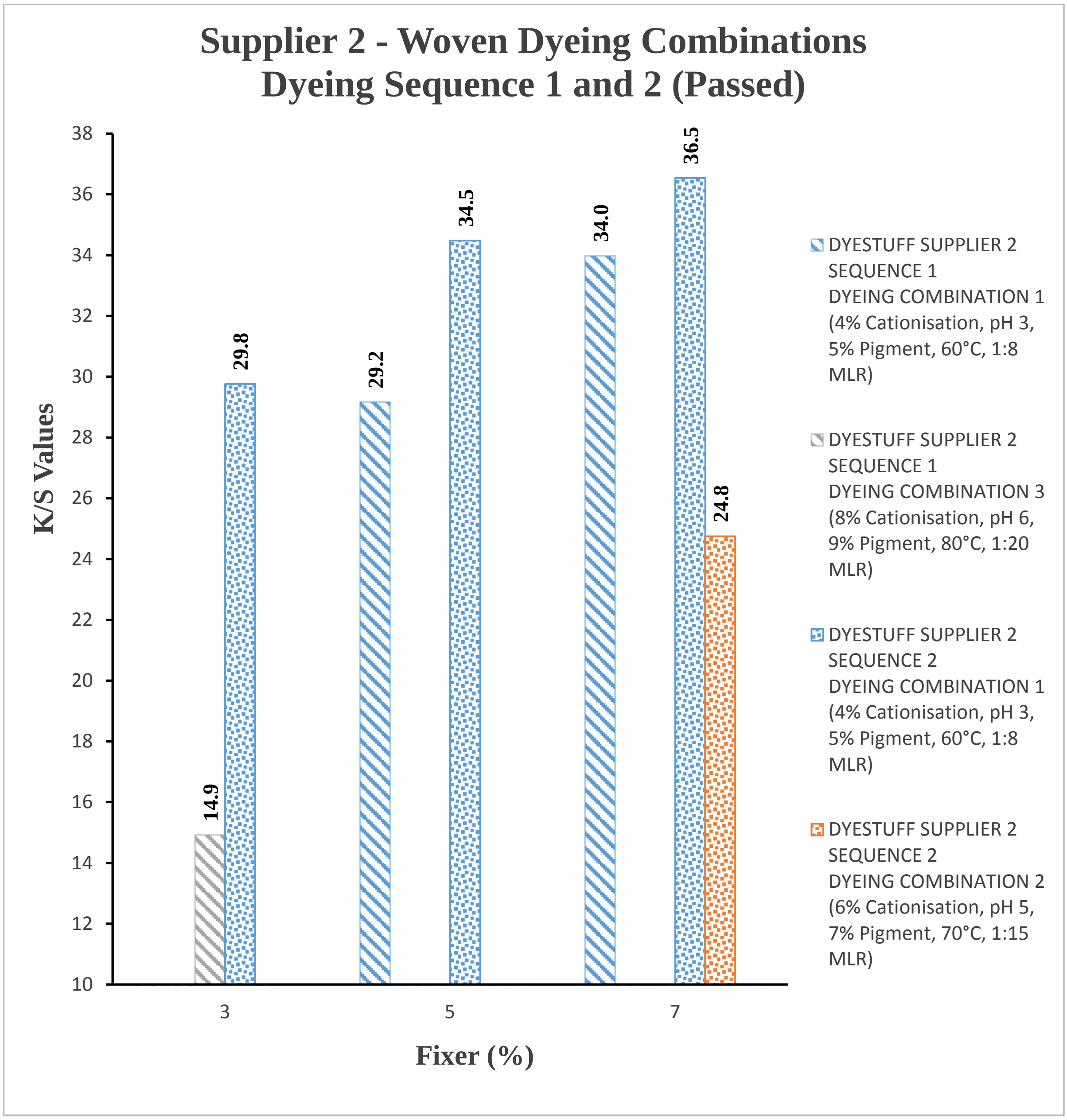


Figure 4.81 Grey Scale Ratings of 3/4 or Higher for Fixer Concentration Trials for Woven Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

4.3.5.8. DISCUSSION

Acceptable pass ratings of 3/4, as indicated in Figures 4.79 and 4.81, showed that sequence 1 obtained a pass rating at 7% fixer for the knitted fabric, and at all fixer levels for the woven fabric, whereas sequence 2 obtained pass ratings at 3 and 7% fixer for the knitted fabric, and at all fixer levels for the woven fabric. The fixer trials for the knitted fabrics, however did not achieve any pass ratings of 4 or higher for all fastness, however, the woven fabric achieved 3 dyeing combinations with pass ratings of 4 or higher for all fastness, for both sequences. Table 4.81, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for the woven fabric being K/S of 36.5 at 7% Fixer for dyeing combination 2, for sequence 2, Supplier 2.

Table 4.81 Ideal Dyeing Combinations for Woven Fabric for Fixer Concentration Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 2																
Fixer Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	7	1:8	34.0	5	5	5	5	5	4	4	4	4
SEQUENCE 2 - SUPPLIER 2																
Fixer Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
2	4	3	5	60	5	1:8	34.5	5	5	5	5	5	4/5	4	4	4
	4	3	5	60	7	1:8	36.5	5	5	5	5	5	4/5	4/5	4/5	4

4.3.5.9. CONCLUSION

To conclude the results for all binder/fixer concentration trials for each supplier and sequence, the average K/S was taken into account. The effect of binder/fixer concentration on K/S, for both knitted and woven fabrics, for both suppliers and sequences showed a decrease in K/S as the binder/fixer concentration increased from 3 to 5 to 7% for all dyeing combinations, while the remaining 5 parameters (cationisation, pH, pigment, temperature and MLR) increased in their respective levels.

The knitted and woven fabric for both suppliers achieved a higher average K/S for dyeing sequence 2 compared to that for dyeing sequence 1. Furthermore, both dyeing sequences for Supplier 2, achieved higher average K/S values compared to that for Supplier 1, for both fabrics. In addition, the K/S values for all woven fabric were higher compared to that for the knitted fabric, with the reasons for this difference being explained in section 4.3.7.

Taking the K/S values into account, it can be concluded that the binder/fixer concentration for the knitted fabric was 7% (K/S of 15.9), for sequence 1 for Supplier 1, while that for the woven fabric was also 7% (K/S of 36.5), for sequence 2 for Supplier 2. In addition, these K/S values also achieved Grey Scale ratings of 4 or higher for all fastness criteria. These ideal binder/fixer concentrations are also close to values by previous work carried out by Patra *et al* (2006), which reported that 5% binder provided the best results in terms of K/S and wet rub.

4.3.6. Effect of MLR Level

The two dyestuff suppliers were compared with one another to determine the effect of MLR on the outcome of K/S and fastness, when the MLR levels were increased from 1:8 to 1:15 to 1:20, while the other 5 parameters (cationisation, pH, pigment, temperature and binder/fixer) were kept constant, per dyeing combination. The MLR level trials consisted of three dyeing combinations, with 3 trials per dyeing combination, and were performed using dyeing sequence 1 and 2. The results from these trials for both suppliers and sequences will be concluded in section 4.3.7. The dyeing combinations used in the trials for MLR are presented in Table 4.82, with the results presented graphically.

Table 4.82 Dyeing Combinations for Material-to-Liquor Ratio Level Trials.

	MLR Level Trials						
	Cationisation (%)	**pH**	**Pigment (%)**	**Temp (°C)**	**Binder/ Fixer (%)**	**MLR**	**Trial No.**
Combination 1	4	3	5	60	3	1:8	1
	4	3	5	60	3	1:15	4
	4	3	5	60	3	1:20	7
Combination 2	6	5	7	70	5	1:8	2
	6	5	7	70	5	1:15	5
	6	5	7	70	5	1:20	8
Combination 3	8	6	9	80	7	1:8	3
	8	6	9	80	7	1:15	6
	8	6	9	80	7	1:20	9

4.3.6.1. SUPPLIERS 1 AND 2 (DYEING SEQUENCE 1)

4.3.6.1.1. Knitted Fabric Results

The K/S for both suppliers is represented in Figure 4.82, which shows that the K/S, for Supplier 2 is higher than that for Supplier 1; with the greatest K/S at MLR of 1:15. Suppliers 1 and 2, shows a decrease in K/S at each level of MLR, as the remaining parameters are increased. Supplier 1, for dyeing combination 3, shows a decrease in K/S as the MLR is increased from 1:8 to 1:15 to 1:20.

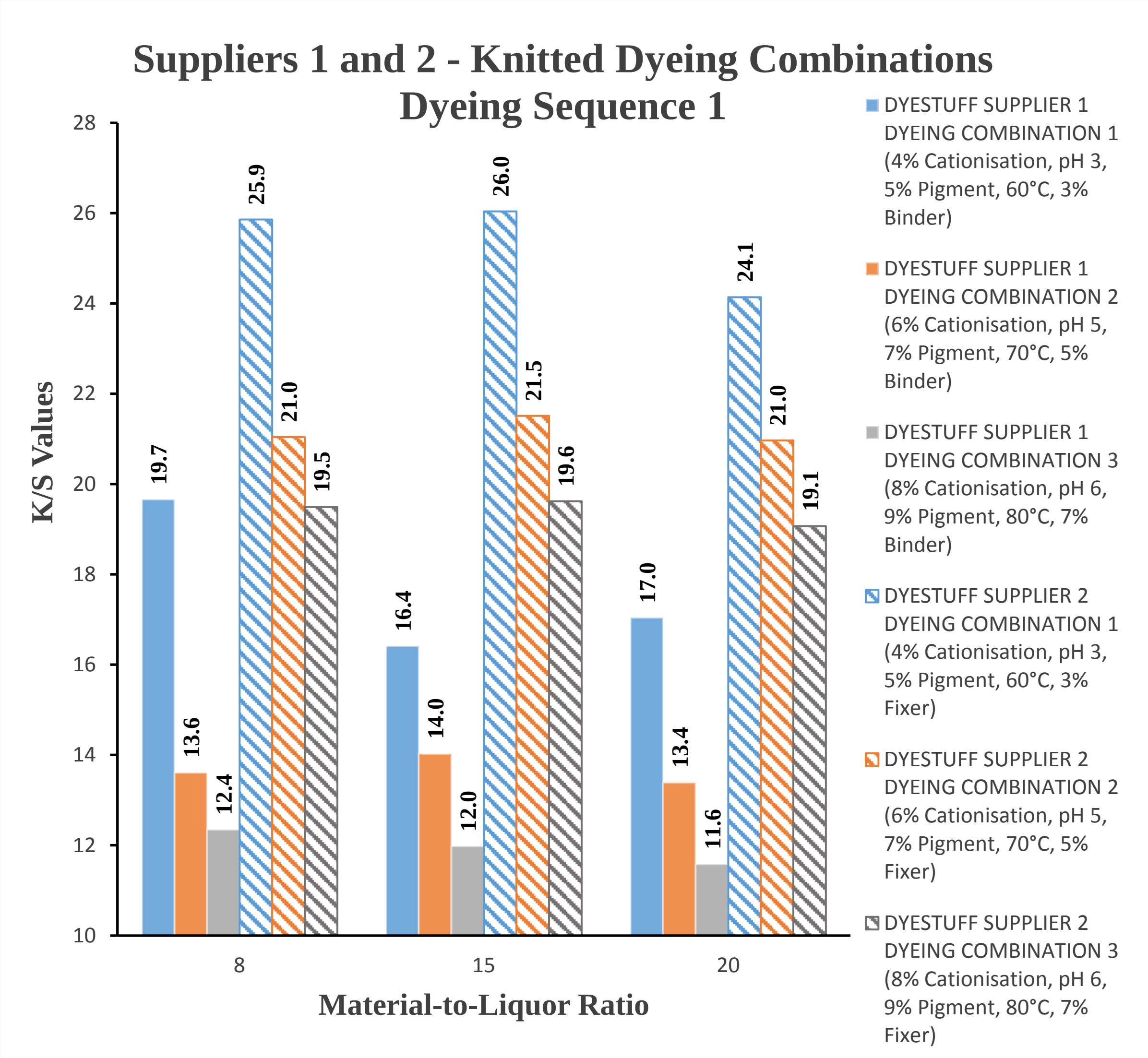


Figure 4.82 Effect of Material-to-Liquor Ratio Level on K/S for the Dyeing Combinations for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

Table 4.83, shows that Supplier 1 achieves acceptable pass ratings of 3/4 for MLR at 1:15 and 1:20 for dyeing combination 1, and at all levels of MLR for dyeing combinations 2 and 3. Supplier 2, achieves acceptable pass ratings for MLR at 1:15 for dyeing combination 1 and at 1:8 for dyeing combination 3. In addition, Figure 4.83 shows the dyeing combinations that have passed in terms of all fastness with a rating of 3/4. Accordingly, both dyestuff suppliers passed in terms of all the fastness criteria, with Supplier 2 achieving higher K/S values than that for Supplier 1.

Table 4.83 Knitted Test Results for MLR Level Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
MLR Trials:							KNITTED										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	19.7	4/5	3/4	4/5	3	3/4	2/3	2/3	2	2/3	17.7	13.8
	4	3	5	60	3	1:15	16.4	4/5	4	4/5	4/5	4/5	3/4	3/4	3/4	3/4		
	4	3	5	60	3	1:20	17.0	4/5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3/4		
2	6	5	7	70	5	1:8	13.6	4/5	4	4/5	4	4/5	3/4	4	3/4	3/4	13.7	
	6	5	7	70	5	1:15	14.0	5	4/5	4/5	4/5	4/5	4	3/4	4	4		
	6	5	7	70	5	1:20	13.4	4/5	4/5	5	5	4/5	3/4	3/4	3/4	3/4		
3	8	6	9	80	7	1:8	12.4	4/5	4/5	5	4/5	4/5	4	4	4	4	12.0	
	8	6	9	80	7	1:15	12.0	4/5	5	5	5	5	4	3/4	3/4	4		
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4		
SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
MLR Trials:							KNITTED										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.9	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3	25.3	21.5
	4	3	5	60	3	1:15	26.0	5	5	5	5	5	4	4/5	4/5	4		
	4	3	5	60	3	1:20	24.1	5	5	5	5	4/5	3	3	3/4	3/4		
2	6	5	7	70	5	1:8	21.0	5	4/5	4/5	5	4/5	4	3	3	3/4	21.2	
	6	5	7	70	5	1:15	21.5	5	4/5	5	5	4/5	3/4	3	3	3		
	6	5	7	70	5	1:20	21.0	5	5	4/5	5	5	3/4	3	2/3	3		
3	8	6	9	80	7	1:8	19.5	5	5	5	4/5	4/5	4	4	4	4	19.4	
	8	6	9	80	7	1:15	19.6	5	5	5	4/5	4/5	3/4	3	4	3		
	8	6	9	80	7	1:20	19.1	5	4/5	4/5	5	5	2/3	2/3	2/3	3		

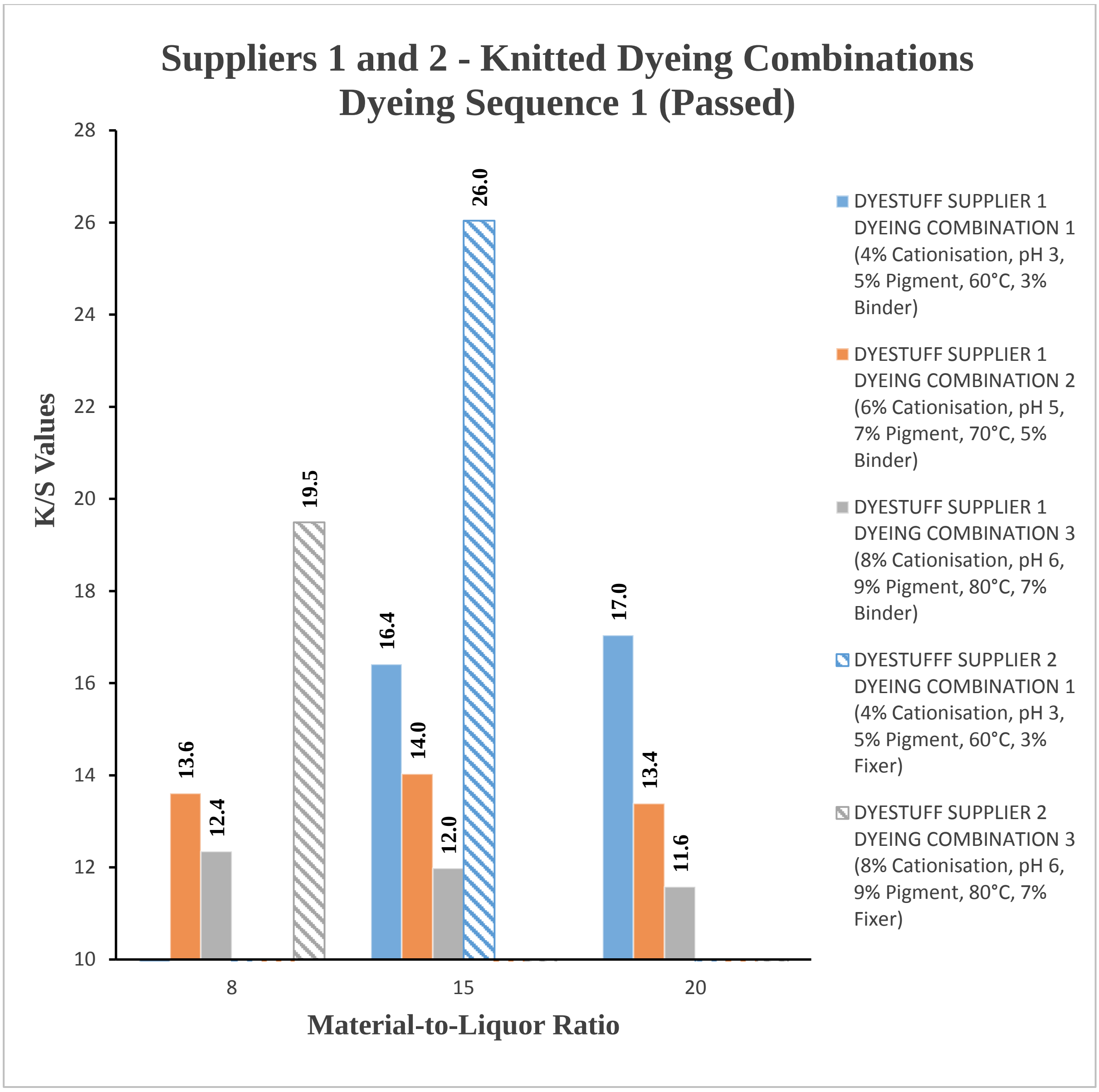


Figure 4.83 Grey Scale Ratings of 3/4 or Higher for Material-to-Liquor Ratio Level Trials for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

4.3.6.1.2. <u>Woven Fabric Results</u>

The K/S for both suppliers is represented in Figure 4.84, which shows that the K/S, for Supplier 2 is greater than that for Supplier 1; with the highest K/S at MLR of 1:15. Suppliers 1 and 2, shows a decrease in K/S at each level of MLR, as the remaining parameters are increased. Supplier 2, for dyeing combination 2, shows a slight decrease in K/S as the MLR is increased from 1:8 to 1:15 to 1:20. The trend, is also identical to that of the MLR trials for the knitted fabric.

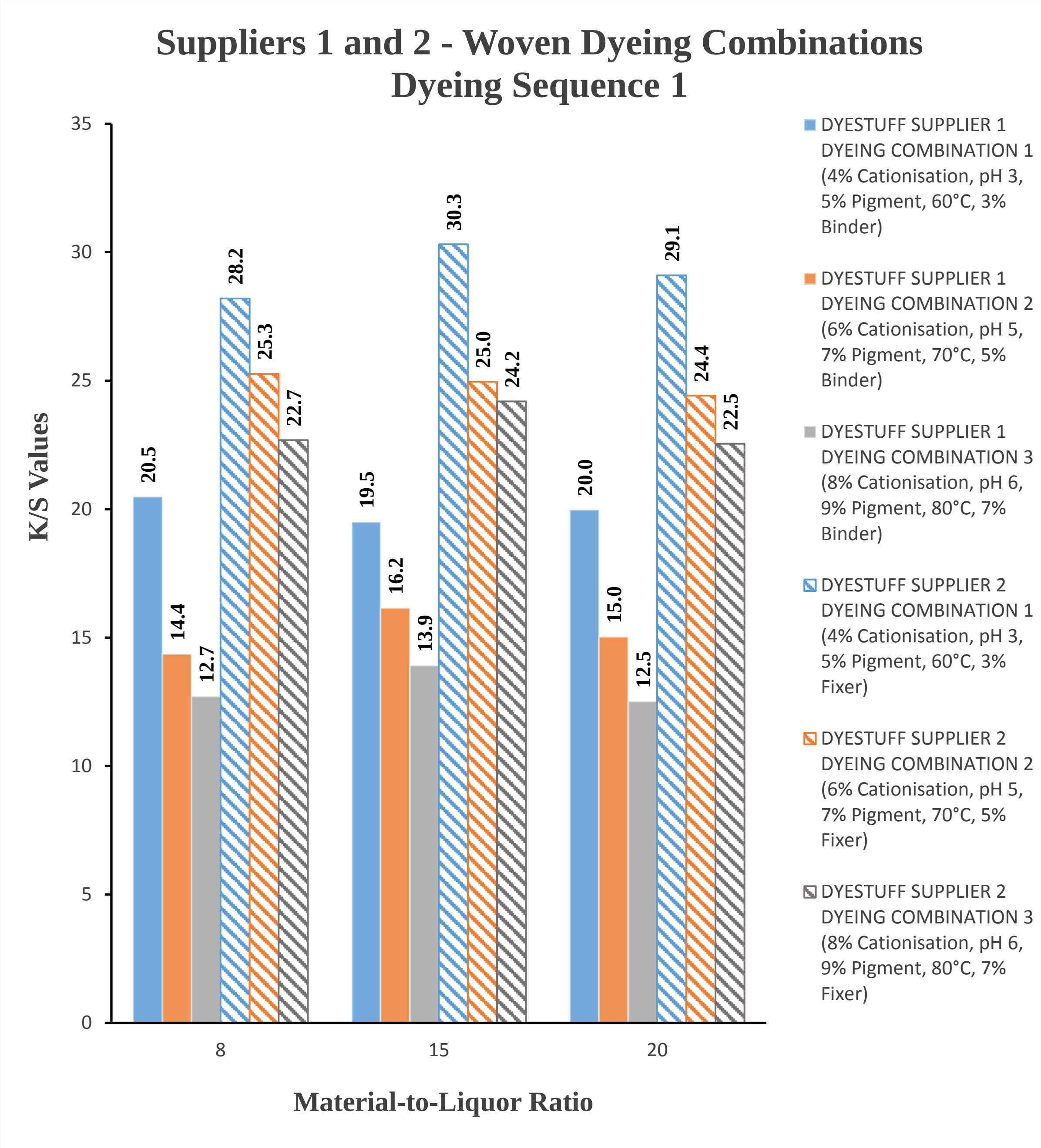


Figure 4.84 Effect of Material-to-Liquor Ratio Level on K/S for the Dyeing Combinations for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 1.

Table 4.84, shows that Supplier 1 achieves acceptable pass ratings of 3/4 at all levels of MLR for all dyeing combinations, however, Supplier 2 achieves the same for MLR at 1:15 and 1:20 for dyeing combination 1, at 1:20 for dyeing combination 2, and at 1:15 for dyeing combination 3. In addition, Figure 4.85 shows the dyeing combinations that have passed in terms of all fastness with a rating of 3/4. Accordingly, both suppliers passed in terms of all the fastness criteria, with K/S values being relatively higher for Supplier 2 than that for Supplier 1.

Table 4.84 Woven Test Results for Material-to-Liquor Ratio Level Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
MLR Trials:							WOVEN										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	20.5	4/5	4/5	4/5	4/5	4/5	4	4/5	3/4	4	20.0	15.5
	4	3	5	60	3	1:15	19.5	4/5	4	4	4/5	4/5	3/4	4	3/4	3/4		
	4	3	5	60	3	1:20	20.0	4/5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3/4		
2	6	5	7	70	5	1:8	14.4	4/5	4/5	4/5	4	4	4	4	3/4	3/4	15.2	
	6	5	7	70	5	1:15	16.2	5	4/5	4/5	4/5	4/5	4/5	4/5	4	3/4		
	6	5	7	70	5	1:20	15.0	4/5	4/5	5	4/5	4/5	3/4	4	3/4	4		
3	8	6	9	80	7	1:8	12.7	4/5	4/5	5	4/5	4/5	4	4	4	4	13.0	
	8	6	9	80	7	1:15	13.9	4/5	5	4/5	5	4/5	4	4	3/4	3/4		
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4		

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
MLR Trials:							WOVEN										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	28.2	5	4/5	4/5	5	4/5	3	3	3	2/3	29.2	25.4
	4	3	5	60	3	1:15	30.3	5	5	4/5	5	5	4/5	4	4/5	4		
	4	3	5	60	3	1:20	29.1	5	5	5	5	5	4	4	3/4	3/4		
2	6	5	7	70	5	1:8	25.3	5	4/5	4/5	4/5	4/5	4	3/4	3/4	3	24.9	
	6	5	7	70	5	1:15	25.0	5	4/5	4/5	5	4/5	3	3	4	4		
	6	5	7	70	5	1:20	24.4	5	5	5	4/5	4/5	4	4	4	3/4		
3	8	6	9	80	7	1:8	22.7	5	4/5	4/5	4/5	4/5	3/4	4	3/4	3	23.1	
	8	6	9	80	7	1:15	24.2	5	5	5	5	5	4	4/5	4/5	4		
	8	6	9	80	7	1:20	22.5	5	5	5	5	4/5	3	4	3/4	3		

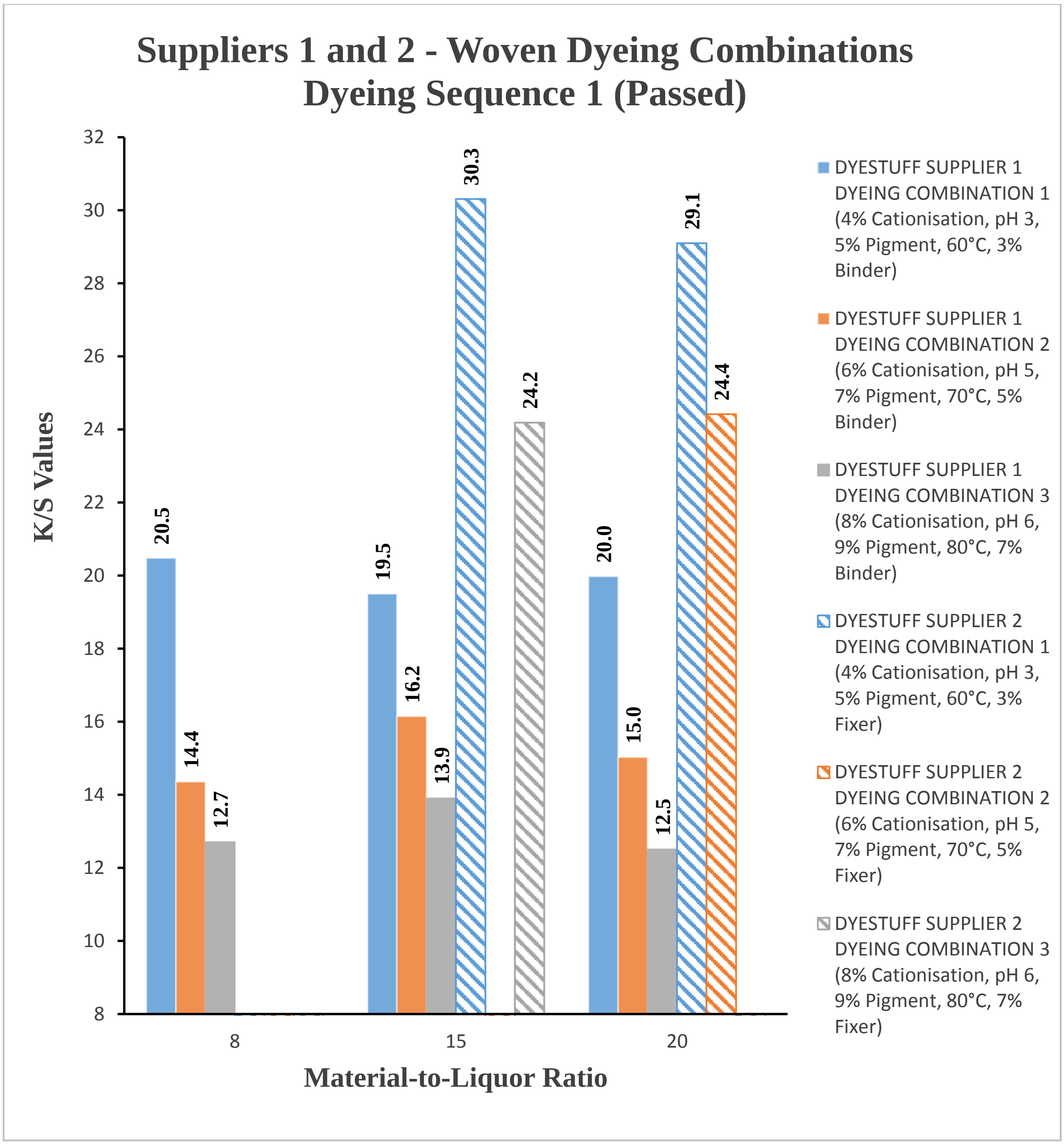


Figure 4.85 Grey Scale Ratings of 3/4 or Higher for Material-to-Liquor Ratio Level Trials for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 1

4.3.6.2. DISCUSSION

Supplier 2 obtained a higher K/S for both fabrics, than that for Supplier 1, with acceptable pass ratings of 3/4, as indicated in Figures 4.83 and 4.85, which showed that Supplier 1 obtained pass ratings at all MLR levels for both fabrics, whereas Supplier 2 obtained pass ratings at MLR of 1:8 and 1:15 for the knitted fabric, and 1:15 and 1:20 for the woven fabric. In addition, 4 dyeing combinations each, for both fabrics for Supplier 1, achieved pass ratings of 4 or higher for all fastness criteria. Tables 4.85 and 4.86, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for the knitted fabric being K/S of 26.0 and woven of 30.3, both at 1:15 MLR for dyeing combination 1, Supplier 2. Once again, the K/S for the woven fabric is higher than that for the knitted fabric.

Table 4.85 Ideal Dyeing Combinations for Knitted Fabric for MLR Level Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - SUPPLIER 1																
MLR Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
3	8	6	9	80	7	1:8	12.4	4/5	4/5	5	4/5	4/5	4	4	4	4
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4
SEQUENCE 1 - SUPPLIER 2																
MLR Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	3	1:15	26.0	5	5	5	5	5	4	4/5	4/5	4
3	8	6	9	80	7	1:8	19.5	5	5	5	4/5	4/5	4	4	4	4

Table 4.86 Ideal Dyeing Combinations for Woven Fabric for MLR Level Trials for Suppliers 1 and 2, Dyeing Sequence 1.

SEQUENCE 1 - SUPPLIER 1																
MLR Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
3	8	6	9	80	7	1:8	12.7	4/5	4/5	5	4/5	4/5	4	4	4	4
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4
SEQUENCE 1 - SUPPLIER 2																
MLR Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	3	1:15	30.3	5	5	4/5	5	5	4/5	4	4/5	4
3	8	6	9	80	7	1:15	24.2	5	5	5	5	5	4	4/5	4/5	4

4.3.6.3. SUPPLIERS 1 AND 2 (DYEING SEQUENCE 2)

4.3.6.3.1. Knitted Fabric Results

The K/S for Suppliers 1 and 2, is represented in Figure 4.86, with the highest K/S seen at a MLR of 1:15 for Supplier 2. All dyeing combinations for Supplier 2, show a decrease in K/S at each level of MLR, as the remaining parameters are increased; with Supplier 1 showing the same at MLR of 1:8 and 1:20. A decrease in K/S is also observed for Supplier 1, dyeing combination 1, and Supplier 2, dyeing combination 2, as the MLR is increase from 1:8 to 1:15 to 1:20.

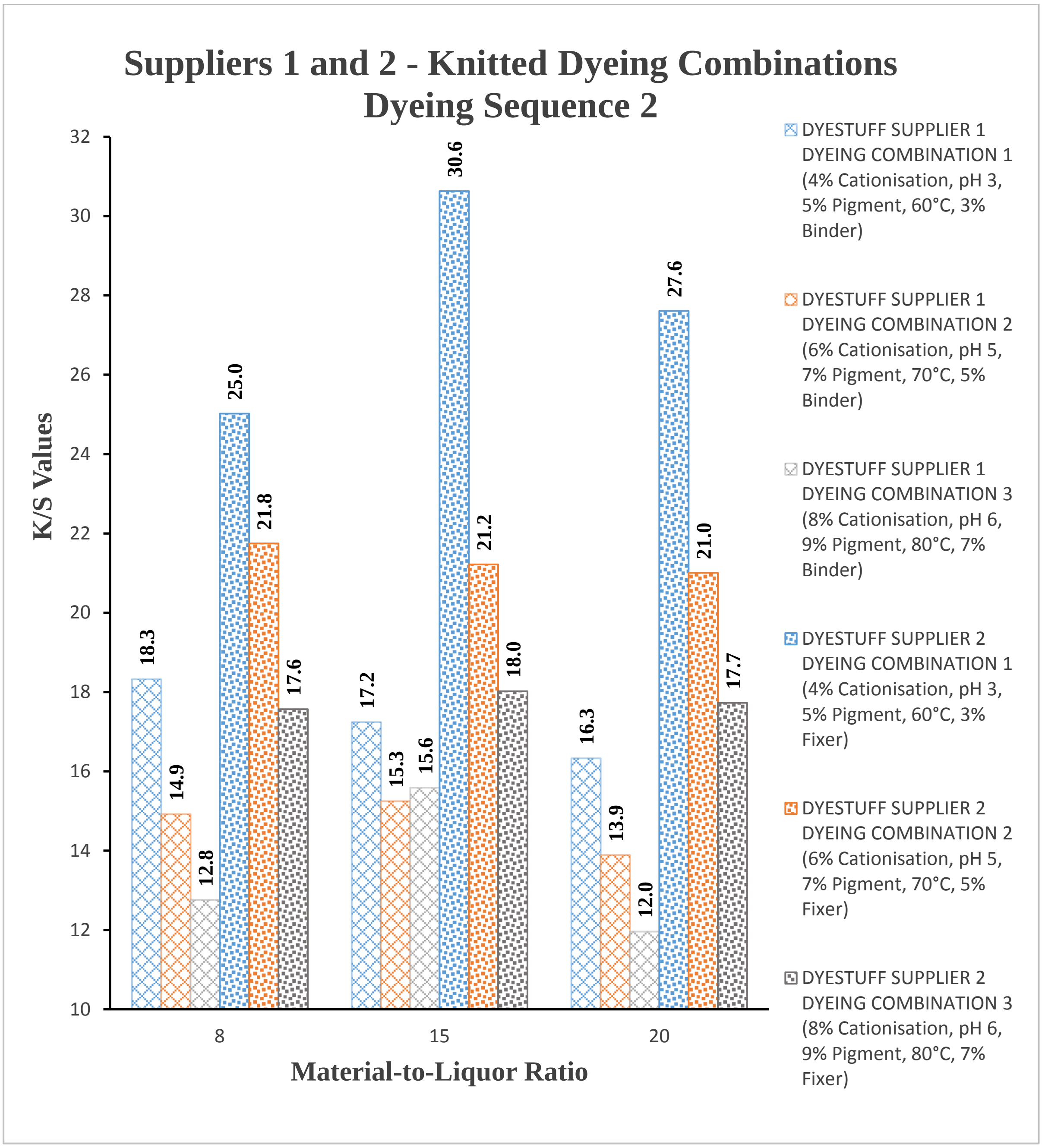


Figure 4.86 Effect of Material-to-Liquor Ratio Level on K/S for the Dyeing Combinations for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

Table 4.87, shows that Supplier 1 does not achieve acceptable pass ratings of 3/4 for MLR for any dyeing combinations, while Supplier 2 achieves acceptable pass ratings for all MLR levels for dyeing combination 1. In addition, Figure 4.87 shows the dyeing combinations that have passed in terms of all fastness with a rating of 3/4.

Table 4.87 Knitted Test Results for MLR Level Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
MLR Trials:							KNITTED										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	18.3	5	4	4	4	4	2/3	2/3	2/3	3	17.3	14.7
	4	3	5	60	3	1:15	17.2	5	4	4	4/5	4/5	3	3	3	3		
	4	3	5	60	3	1:20	16.3	5	4	4/5	4	4/5	3	2/3	2/3	3		
2	6	5	7	70	5	1:8	14.9	5	4/5	4	4/5	4/5	3/4	3/4	3	3	14.7	
	6	5	7	70	5	1:15	15.3	5	4/5	4/5	4/5	4/5	3/4	3	3	3/4		
	6	5	7	70	5	1:20	13.9	5	4	4	4/5	4	3	3	3	2/3		
3	8	6	9	80	7	1:8	12.8	4/5	4/5	4/5	4/5	4	3/4	3	3	3/4	13.4	
	8	6	9	80	7	1:15	15.6	5	4	4	4	4	2/3	2/3	3	3		
	8	6	9	80	7	1:20	12.0	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3		
SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
MLR Trials:							KNITTED										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	25.0	5	4/5	5	5	5	3/4	4	4	4	27.8	21.9
	4	3	5	60	3	1:15	30.6	5	5	5	5	5	4/5	4/5	4	4		
	4	3	5	60	3	1:20	27.6	5	4/5	5	5	5	3/4	3/4	4	3/4		
2	6	5	7	70	5	1:8	21.8	5	5	5	5	5	2/3	2/3	3	4	21.3	
	6	5	7	70	5	1:15	21.2	5	4	4	4/5	4/5	2/3	2/3	2	3		
	6	5	7	70	5	1:20	21.0	5	5	5	5	5	3	2/3	3	3		
3	8	6	9	80	7	1:8	17.6	4/5	4/5	4/5	4/5	4/5	3	2/3	3	3	17.8	
	8	6	9	80	7	1:15	18.0	5	4/5	4/5	4/5	4/5	3/4	3	3/4	3/4		
	8	6	9	80	7	1:20	17.7	5	4/5	4/5	5	4/5	2/3	2	2	2/3		

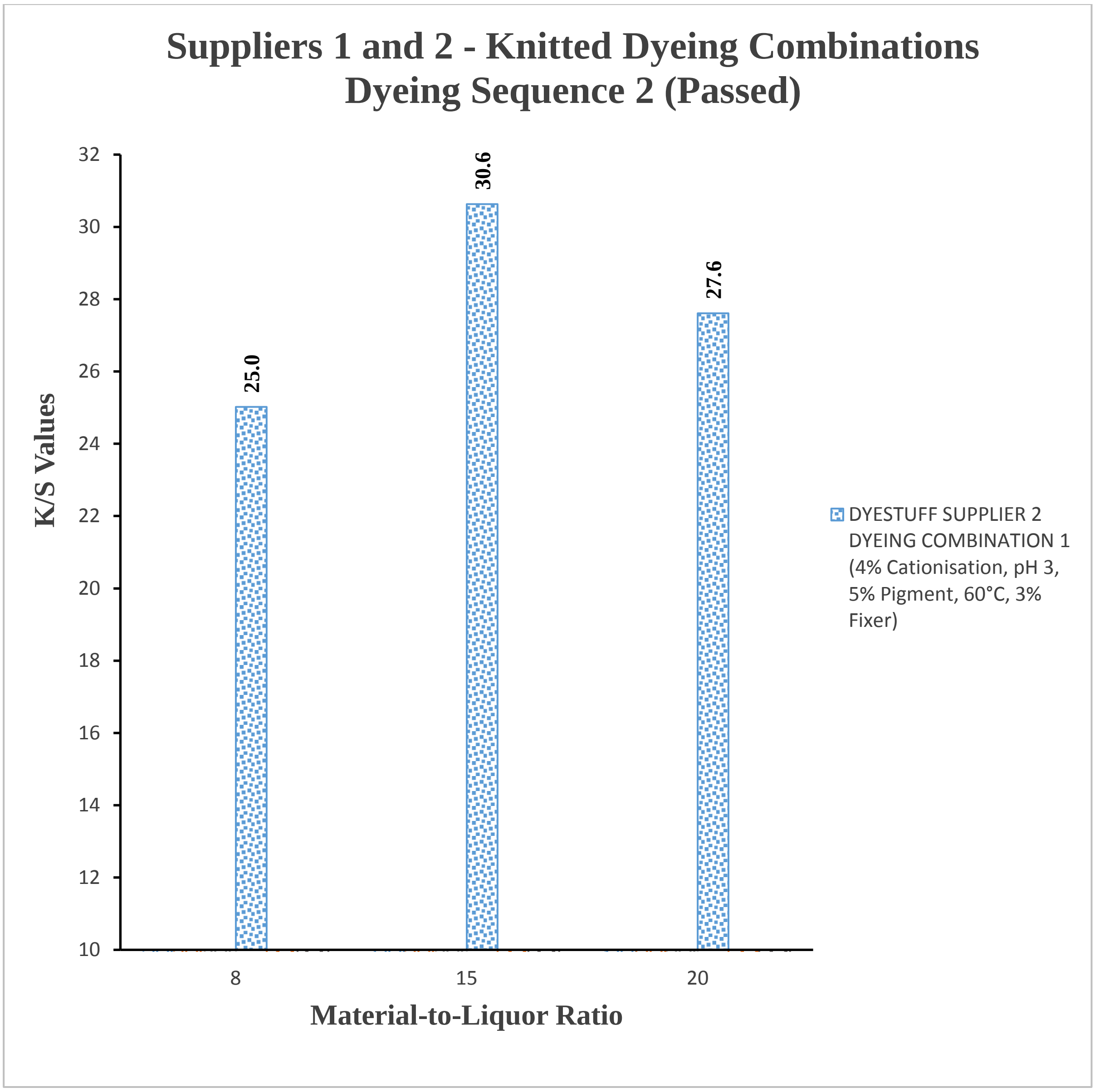


Figure 4.87 Grey Scale Ratings of 3/4 or Higher for Material-to-Liquor Ratio Level Trials for Knitted Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

4.3.6.3.2. Woven Fabric Results

The K/S for Suppliers 1 and 2 is represented in Figure 4.88, with the highest K/S seen at MLR of 1:15 for Supplier 2. All dyeing combinations for Suppliers 1 and 2, show a decrease in K/S at each MLR level, as the remaining parameters are increased. Furthermore, Supplier 1, show a decrease in K/S for dyeing combination 1, as the MLR is increased from 1:8 to 1:15.

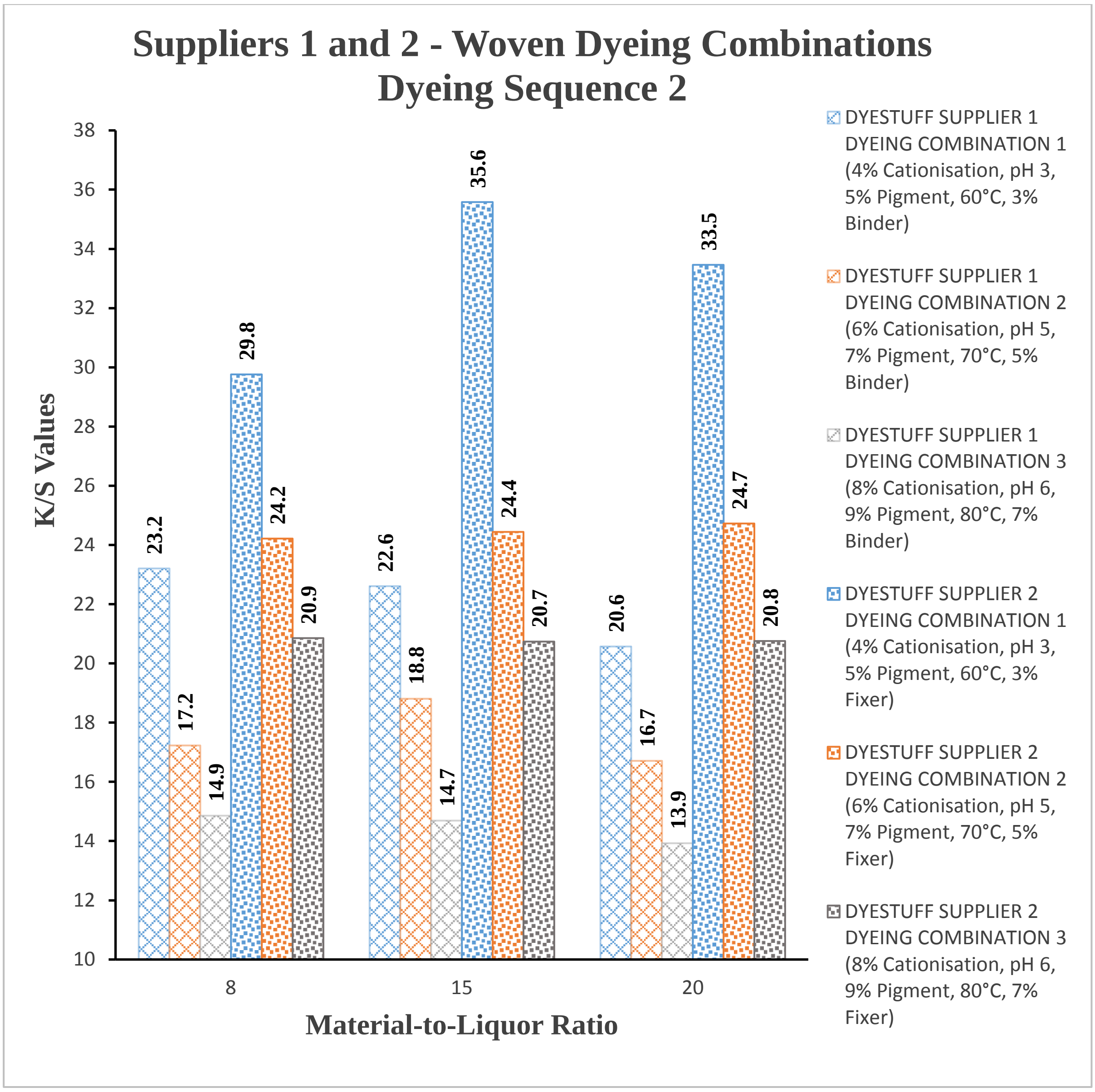


Figure 4.88 Effect of Material-to-Liquor Ratio Level on K/S for the Dyeing Combinations for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

Table 4.88, shows that Supplier 1 achieves an acceptable pass rating of 3/4 for MLR at 1:15 for dyeing combination 1, while Supplier 2, achieves the same at all MLR levels for dyeing combination 1, and at 1:20 for dyeing combination 2, as well as at 1:15 for dyeing combination 3. In addition, Figure 4.89 shows the dyeing combinations that have passed in terms of all fastness with a rating of 3/4.

Table 4.88 Woven Test Results for MLR Level Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
MLR Trials:							WOVEN										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub Face	Warp Dry Rub Back	Weft Dry Rub Face	Weft Dry Rub Back	Warp Wet Rub Face	Warp Wet Rub Back	Weft Wet Rub Face	Weft Wet Rub Back		
1	4	3	5	60	3	1:8	23.2	5	4/5	4/5	4/5	4/5	3	3	3	3	22.1	17.4
	4	3	5	60	3	1:15	22.6	5	4/5	4	4/5	4	3/4	3/4	3/4	3/4		
	4	3	5	60	3	1:20	20.6	4/5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3		
2	6	5	7	70	5	1:8	17.2	5	4/5	4/5	4/5	4/5	4	3	3	3	17.6	
	6	5	7	70	5	1:15	18.8	5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3		
	6	5	7	70	5	1:20	16.7	4/5	4/5	4/5	4/5	4/5	3	3	3/4	3/4		
3	8	6	9	80	7	1:8	14.9	5	4/5	4/5	4/5	4/5	3	3	3	3	14.5	
	8	6	9	80	7	1:15	14.7	4/5	4/5	4/5	4/5	4/5	3	3	3/4	3		
	8	6	9	80	7	1:20	13.9	4/5	4/5	4/5	4/5	4/5	3/4	3	3	3		

SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
MLR Trials:							WOVEN										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub Face	Warp Dry Rub Back	Weft Dry Rub Face	Weft Dry Rub Back	Warp Wet Rub Face	Warp Wet Rub Back	Weft Wet Rub Face	Weft Wet Rub Back		
1	4	3	5	60	3	1:8	29.8	5	5	5	5	5	4	4	3/4	3/4	32.9	25.6
	4	3	5	60	3	1:15	35.6	5	5	5	5	5	4/5	4/5	4/5	4/5		
	4	3	5	60	3	1:20	33.5	5	5	5	5	5	4	4	4	4		
2	6	5	7	70	5	1:8	24.2	5	5	5	5	5	3/4	3	3	3	24.5	
	6	5	7	70	5	1:15	24.4	5	5	5	5	5	3/4	3	3	4		
	6	5	7	70	5	1:20	24.7	5	5	5	5	5	3/4	3/4	3/4	3/4		
3	8	6	9	80	7	1:8	20.9	4/5	4/5	4/5	5	4/5	3/4	3/4	3	3	20.8	
	8	6	9	80	7	1:15	20.7	5	5	5	5	5	4	4	4	4		
	8	6	9	80	7	1:20	20.8	5	5	5	5	5	3	3	3	2		

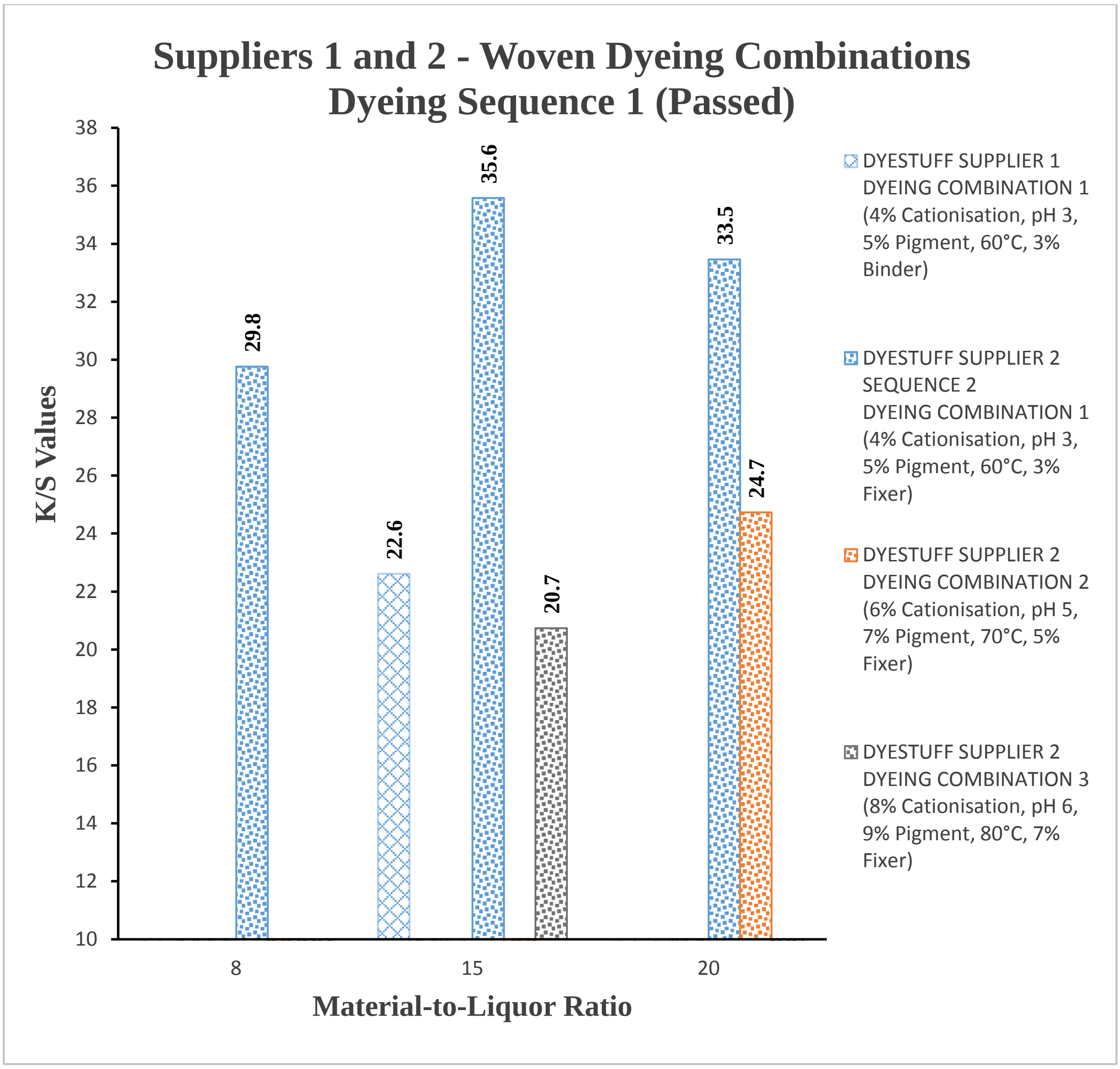


Figure 4.89 Grey Scale Ratings of 3/4 or Higher for Material-to-Liquor Ratio Level Trials for Woven Fabrics for Suppliers 1 and 2, Dyeing Sequence 2.

4.3.6.4. DISCUSSION

Supplier 2 obtained a higher K/S for both fabrics, than that for Supplier 1, with acceptable pass ratings of 3/4, as indicated in Figures 4.87 and 4.89, which showed that Supplier 1 only obtained a pass rating at 1:15 MLR for the woven fabric, while Supplier 2 obtained pass ratings at all MLR levels for both fabrics. However, the knitted fabric had no dyeing combinations that achieved pass ratings of 4 or higher for all fastness criteria, while the woven fabric achieved 3 dyeing combinations with a pass of 4 or higher for all fastness criteria. Table 4.89, represents the dyeing combinations for the woven fabric that achieved a Grey Scale rating of 4 or higher, with the ideal choice being K/S of 35.6 at 1:15 MLR for dyeing combination 1, sequence 2, Supplier 2.

Table 4.89 Ideal Dyeing Combinations for Woven Fabric for MLR Level Trials for Suppliers 1 and 2, Dyeing Sequence 2.

SEQUENCE 2 - SUPPLIER 2																		
MLR Trials:							WOVEN											
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:15	35.6	5	5	5	5	5	4/5	4/5	4/5	4/5		
	4	3	5	60	3	1:20	33.5	5	5	5	5	5	4	4	4	4		
3	8	6	9	80	7	1:15	20.7	5	5	5	5	5	4	4	4	4		

4.3.6.5. SUPPLIER 1 (DYEING SEQUENCE 1 AND 2)

4.3.6.5.1. Knitted Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.90, with the highest K/S seen at an MLR of 1:8 for dyeing sequence 1. All dyeing combinations for sequence 1, show a decrease in K/S at each MLR level, as the level of the remaining parameters are increased, while sequence 2 exhibits the same trend for all dyeing combinations at MLR of 1:8 and 1:20. Sequence 1, dyeing combinations 3, and sequence 2, dyeing combination 1, shows a decrease in K/S as the MLR is increased from 1:8 to 1:15 to 1:20.

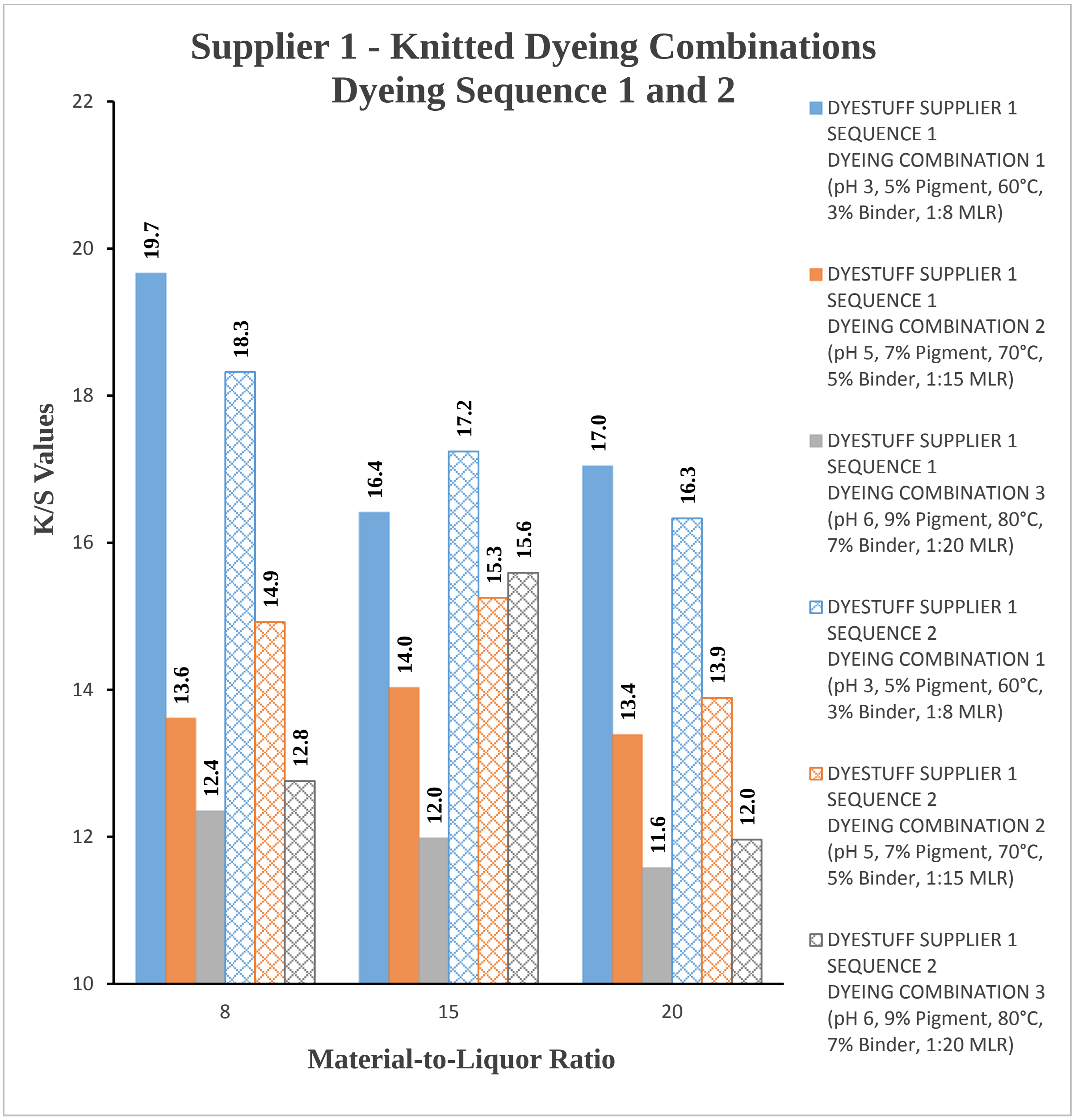


Figure 4.90 Effect of Material-to-Liquor Ratio Level on K/S for the Dyeing Combinations for Knitted Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

Table 4.90, shows that sequence 1 achieves acceptable pass ratings at an MLR of 1:15 and 1:20 for dyeing combination 1, and at all MLR levels for dyeing combinations 2 and 3; while sequence 2 does not obtain any pass at all levels of MLR for all dyeing combinations. In addition, Figure 4.91 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, sequence 1 obtains a pass at all MLR levels, however with a relatively lower K/S than those achieved in the MLR trials.

Table 4.90 Knitted Test Results for MLR Level Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 1																		
MLR Trials:							KNITTED										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub Face	Warp Dry Rub Back	Weft Dry Rub Face	Weft Dry Rub Back	Warp Wet Rub Face	Warp Wet Rub Back	Weft Wet Rub Face	Weft Wet Rub Back		
1	4	3	5	60	3	1:8	19.7	4/5	3/4	4/5	3	3/4	2/3	2/3	2	2/3	17.7	13.8
	4	3	5	60	3	1:15	16.4	4/5	4	4/5	4/5	4/5	3/4	3/4	3/4	3/4		
	4	3	5	60	3	1:20	17.0	4/5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3/4		
2	6	5	7	70	5	1:8	13.6	4/5	4	4/5	4	4/5	3/4	4	3/4	3/4	13.7	
	6	5	7	70	5	1:15	14.0	5	4/5	4/5	4/5	4/5	4	3/4	4	4		
	6	5	7	70	5	1:20	13.4	4/5	4/5	5	5	4/5	3/4	3/4	3/4	3/4		
3	8	6	9	80	7	1:8	12.4	4/5	4/5	5	4/5	4/5	4	4	4	4	12.0	
	8	6	9	80	7	1:15	12.0	4/5	5	5	5	5	4	3/4	3/4	4		
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4		
SEQUENCE 2 - DYESTUFF SUPPLIER 1																		
MLR Trials:							KNITTED										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub Face	Warp Dry Rub Back	Weft Dry Rub Face	Weft Dry Rub Back	Warp Wet Rub Face	Warp Wet Rub Back	Weft Wet Rub Face	Weft Wet Rub Back		
1	4	3	5	60	3	1:8	18.3	5	4	4	4	4	2/3	2/3	2/3	3	17.3	14.7
	4	3	5	60	3	1:15	17.2	5	4	4	4/5	4/5	3	3	3	3		
	4	3	5	60	3	1:20	16.3	5	4	4/5	4	4/5	3	2/3	2/3	3		
2	6	5	7	70	5	1:8	14.9	5	4/5	4	4/5	4/5	3/4	3/4	3	3	14.7	
	6	5	7	70	5	1:15	15.3	5	4/5	4/5	4/5	4/5	3/4	3	3	3/4		
	6	5	7	70	5	1:20	13.9	5	4	4	4/5	4	3	3	3	2/3		
3	8	6	9	80	7	1:8	12.8	4/5	4/5	4/5	4/5	4	3/4	3	3	3/4	13.4	
	8	6	9	80	7	1:15	15.6	5	4	4	4	4	2/3	2/3	3	3		
	8	6	9	80	7	1:20	12.0	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3		

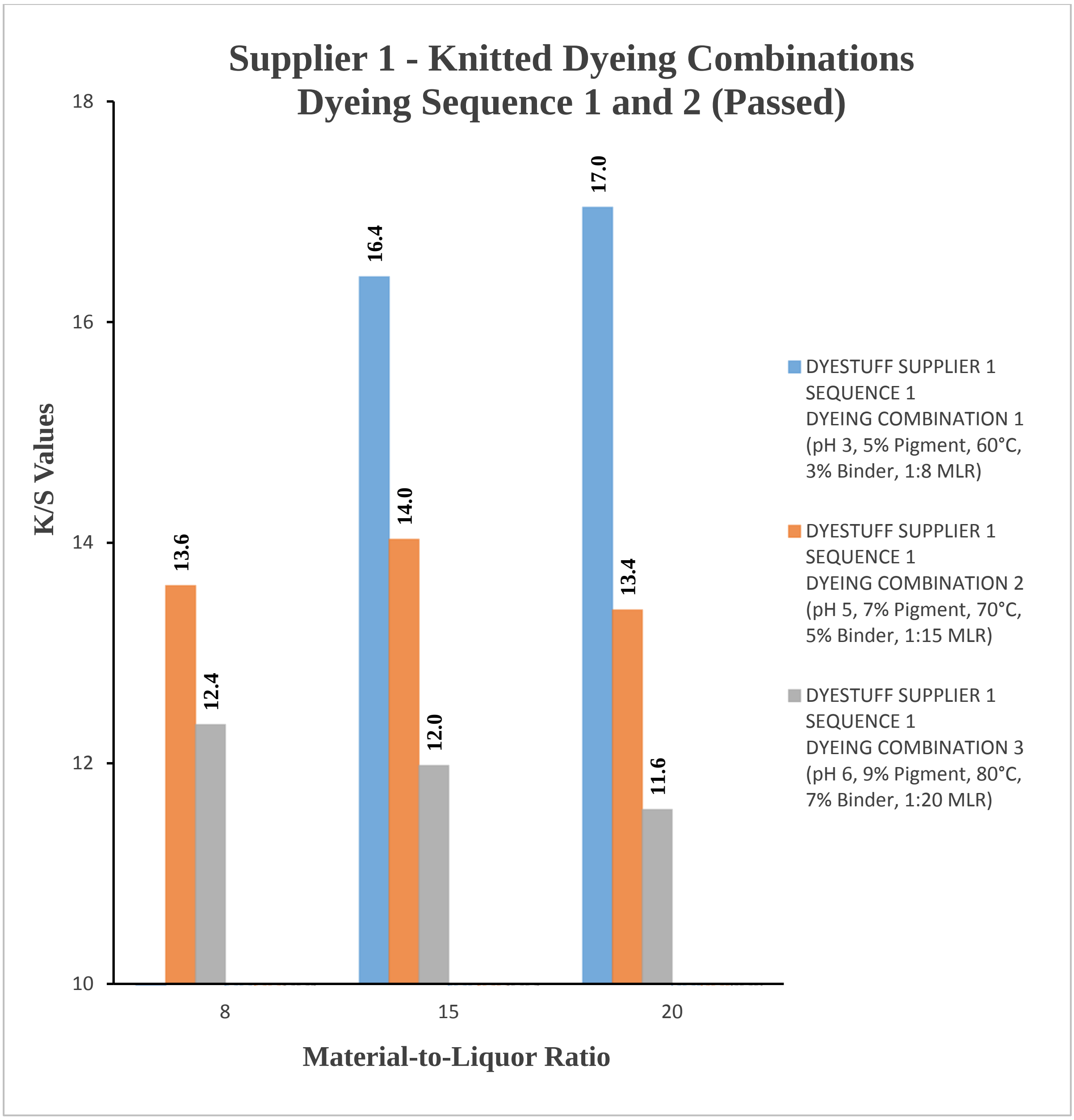


Figure 4.91 Grey Scale Ratings of 3/4 or Higher for Material-to-Liquor Ratio Level Trials for Knitted Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

4.3.6.5.2. Woven Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.92, with the highest K/S seen at an MLR of 1:8 for dyeing sequence 2. All dyeing combinations for sequence 1 and 2, show a decrease in K/S at each MLR level, as the level of the remaining parameters are increased. Sequence 2, dyeing combinations 1 and 3 show a decrease in K/S as the MLR is increased from 1:8 to 1:15 to 1:20.

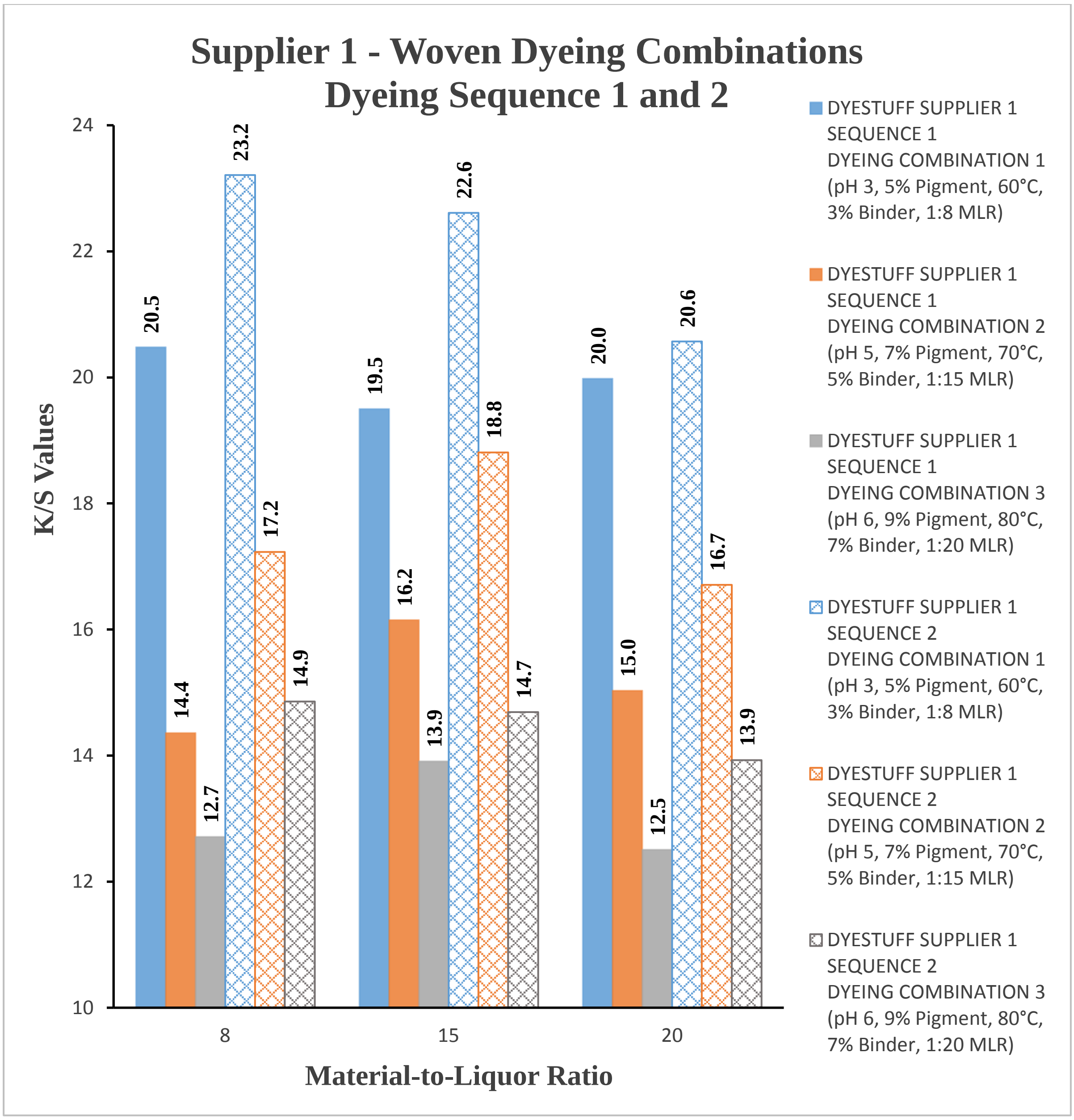


Figure 4.92 Effect of Material-to-Liquor Ratio Level on K/S for the Dyeing Combinations for Woven Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

Table 4.91, shows that sequence 1 achieves acceptable pass ratings at all MLR levels for all dyeing combinations, while sequence 2 obtains the same at MLR 1:15 for dyeing combination 1. In addition, Figure 4.93 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, sequence 1 obtains a pass at all MLR levels, with K/S values slightly lower than that for sequence 2.

Table 4.91 Woven Test Results for MLR Level Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 1

MLR Trials:							WOVEN										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	20.5	4/5	4/5	4/5	4/5	4/5	4	4/5	3/4	4	20.0	15.5
	4	3	5	60	3	1:15	19.5	4/5	4	4	4/5	4/5	3/4	4	3/4	3/4		
	4	3	5	60	3	1:20	20.0	4/5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3/4		
2	6	5	7	70	5	1:8	14.4	4/5	4/5	4/5	4	4	4	4	3/4	3/4	15.2	
	6	5	7	70	5	1:15	16.2	5	4/5	4/5	4/5	4/5	4/5	4/5	4	3/4		
	6	5	7	70	5	1:20	15.0	4/5	4/5	5	4/5	4/5	3/4	4	3/4	4		
3	8	6	9	80	7	1:8	12.7	4/5	4/5	5	4/5	4/5	4	4	4	4	13.0	
	8	6	9	80	7	1:15	13.9	4/5	5	4/5	5	4/5	4	4	3/4	3/4		
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4		

SEQUENCE 2 - DYESTUFF SUPPLIER 1

MLR Trials:							WOVEN										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	23.2	5	4/5	4/5	4/5	4/5	3	3	3	3	22.1	17.4
	4	3	5	60	3	1:15	22.6	5	4/5	4	4/5	4	3/4	3/4	3/4	3/4		
	4	3	5	60	3	1:20	20.6	4/5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3		
2	6	5	7	70	5	1:8	17.2	5	4/5	4/5	4/5	4/5	4	3	3	3	17.6	
	6	5	7	70	5	1:15	18.8	5	4/5	4/5	4/5	4/5	3/4	3/4	3/4	3		
	6	5	7	70	5	1:20	16.7	4/5	4/5	4/5	4/5	4/5	3	3	3/4	3/4		
3	8	6	9	80	7	1:8	14.9	5	4/5	4/5	4/5	4/5	3	3	3	3	14.5	
	8	6	9	80	7	1:15	14.7	4/5	4/5	4/5	4/5	4/5	3	3	3/4	3		
	8	6	9	80	7	1:20	13.9	4/5	4/5	4/5	4/5	4/5	3/4	3	3	3		

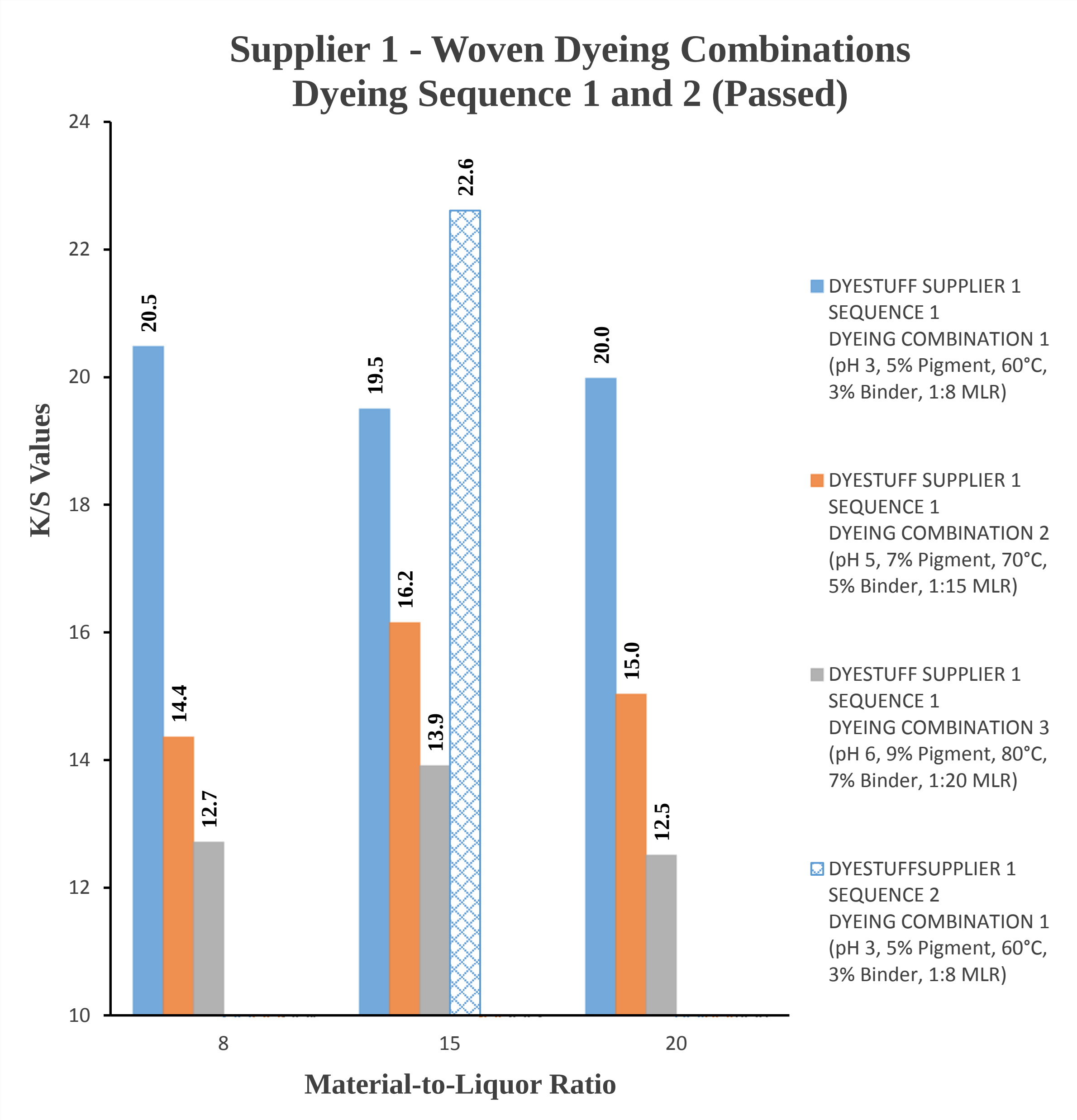


Figure 4.93 Grey Scale Ratings of 3/4 or Higher for Material-to-Liquor Ratio Level Trials for Woven Fabrics for Supplier 1, Dyeing Sequence 1 and 2.

4.3.6.6. DISCUSSION

Sequence 2 for dyeing combinations 2 and 3 obtained a higher K/S than sequence 1. Acceptable pass ratings of 3/4, as indicated in Figures 4.91 and 4.93, showed that sequence 1 obtained pass ratings at all levels of MLR for the knitted and woven fabrics, whereas sequence 2 only achieved a pass rating at 1:15 MLR for the woven fabric. In addition, 2 dyeing combinations each, for sequence 1, achieved pass ratings of 4 or higher for all fastness criteria. Tables 4.92 and 4.93, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for knitted being K/S of 12.4, and that of the woven being K/S of 12.7, both at 1:8 MLR for dyeing combination 3, sequence 1, Supplier 1.

Table 4.92 Ideal Dyeing Combinations for Knitted Fabric for MLR Level Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 1																
MLR Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
3	8	6	9	80	7	1:8	12.4	4/5	4/5	5	4/5	4/5	4	4	4	4
	8	6	9	80	7	1:20	11.6	5	4/5	4/5	4/5	4/5	4/5	4	4	4

Table 4.93 Ideal Dyeing Combinations for Woven Fabric for MLR Level Trials for Supplier 1, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 1																
MLR Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
3	8	6	9	80	7	1:8	12.7	4/5	4/5	5	4/5	4/5	4	4	4	4
	8	6	9	80	7	1:20	12.5	5	4/5	4/5	4/5	4/5	4	4/5	4	4

4.3.6.7. SUPPLIER 2 (DYEING SEQUENCE 1 AND 2)

4.3.6.7.1. Knitted Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.94, with the highest K/S seen at MLR of 1:15 for dyeing sequence 2. All dyeing combinations for sequence 1 and 2, show a decrease in K/S at each MLR level, as the level of the remaining parameters are increased. The visible trend is for sequence 1 and 2, whereby dyeing combinations 1 and 2 for sequence 1 show an increase in K/S followed by a decrease in K/S, with dyeing combination 3 showing a decrease in K/S, as the MLR is increased from 1:8 to 1:15 to 1:20. Sequence 2, dyeing combinations 1 and 3 also shows an increase in K/S followed by a decrease in K/S, with dyeing combination 2 showing a decrease in K/S as the MLR is increased from 1:8 to 1:15 to 1:20.

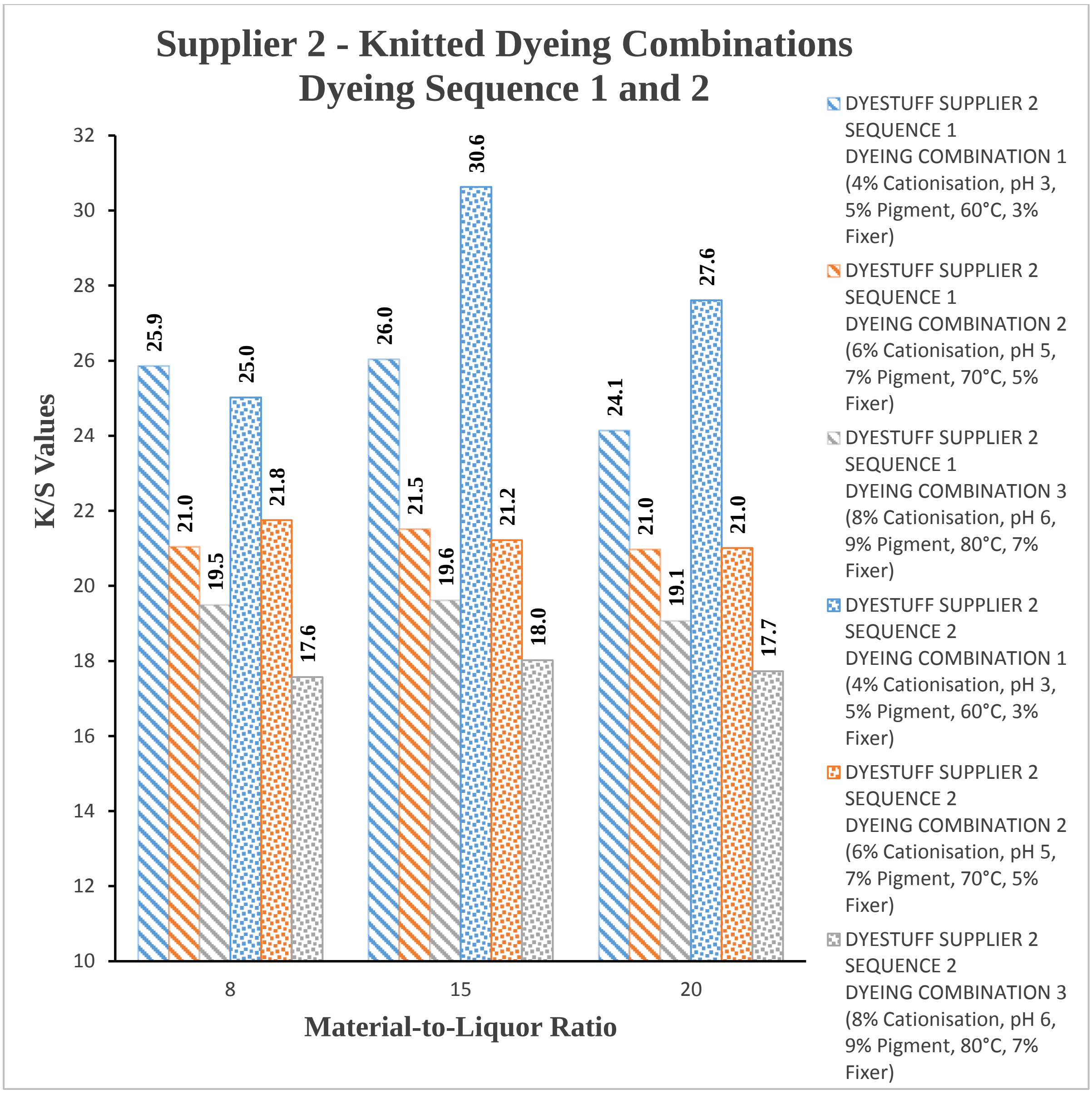


Figure 4.94 Effect of Material-to-Liquor Ratio Level on K/S for the Dyeing Combinations for Knitted Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

Table 4.94, shows that sequence 1 achieves acceptable pass ratings of 3/4 at MLR of 1:15 for dyeing combination 1 and at MLR of 1:8 for dyeing combination 3, while sequence 2 obtains the same at all levels of MLR for dyeing combination 1 only. In addition, Figure 4.95 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, sequence 2 obtains a pass at all MLR levels, with a higher K/S than that for sequence 1.

Table 4.94 Knitted Test Results for MLR Level Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 2

MLR Trials:							KNITTED										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub Face	Warp Dry Rub Back	Weft Dry Rub Face	Weft Dry Rub Back	Warp Wet Rub Face	Warp Wet Rub Back	Weft Wet Rub Face	Weft Wet Rub Back		
1	4	3	5	60	3	1:8	25.9	5	4/5	4/5	4/5	4/5	2/3	2	2	2/3	25.3	21.5
	4	3	5	60	3	1:15	26.0	5	5	5	5	5	4	4/5	4/5	4		
	4	3	5	60	3	1:20	24.1	5	5	5	5	4/5	3	3	3/4	3/4		
2	6	5	7	70	5	1:8	21.0	5	4/5	4/5	5	4/5	4	3	3	3/4	21.2	
	6	5	7	70	5	1:15	21.5	5	4/5	5	5	4/5	3/4	3	3	3		
	6	5	7	70	5	1:20	21.0	5	5	4/5	5	5	3/4	3	2/3	3		
3	8	6	9	80	7	1:8	19.5	5	5	5	4/5	4/5	4	4	4	4	19.4	
	8	6	9	80	7	1:15	19.6	5	5	5	4/5	4/5	3/4	3	4	3		
	8	6	9	80	7	1:20	19.1	5	4/5	4/5	5	5	2/3	2/3	2/3	3		

SEQUENCE 2 - DYESTUFF SUPPLIER 2

MLR Trials:							KNITTED										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub Face	Warp Dry Rub Back	Weft Dry Rub Face	Weft Dry Rub Back	Warp Wet Rub Face	Warp Wet Rub Back	Weft Wet Rub Face	Weft Wet Rub Back		
1	4	3	5	60	3	1:8	25.0	5	4/5	5	5	5	3/4	4	4	4	27.8	21.9
	4	3	5	60	3	1:15	30.6	5	5	5	5	5	4/5	4/5	4	4		
	4	3	5	60	3	1:20	27.6	5	4/5	5	5	5	3/4	3/4	4	3/4		
2	6	5	7	70	5	1:8	21.8	5	5	5	5	5	2/3	2/3	3	4	21.3	
	6	5	7	70	5	1:15	21.2	5	4	4	4/5	4/5	2/3	2/3	2	3		
	6	5	7	70	5	1:20	21.0	5	5	5	5	5	3	2/3	3	3		
3	8	6	9	80	7	1:8	17.6	4/5	4/5	4/5	4/5	4/5	3	2/3	3	3	17.8	
	8	6	9	80	7	1:15	18.0	5	4/5	4/5	4/5	4/5	3/4	3	3/4	3/4		
	8	6	9	80	7	1:20	17.7	5	4/5	4/5	5	4/5	2/3	2	2	2/3		

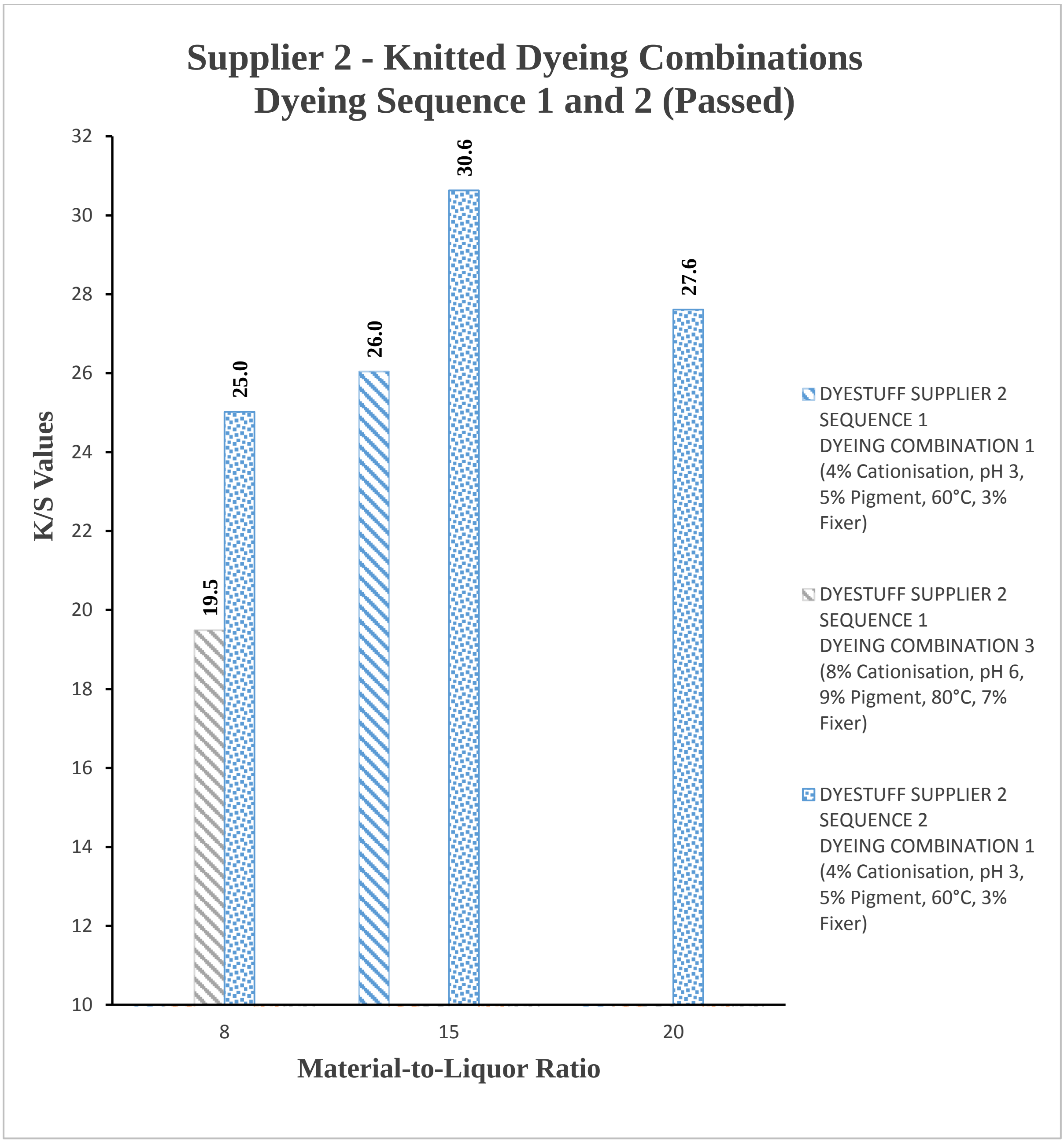


Figure 4.95 Grey Scale Ratings of 3/4 or Higher for Material-to-Liquor Ratio Level Trials for Knitted Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

4.3.6.7.2. Woven Fabric Results

The K/S for dyeing sequence 1 and 2 is represented in Figure 4.96, with the highest K/S seen at MLR of 1:15 for dyeing sequence 2. All dyeing combinations for sequence 1 and 2, show a decrease in K/S at each MLR level, as the level of the remaining parameters are increased. A trend is visible for sequence 1 and 2, whereby dyeing combinations 1 and 3 for sequence 1 show an increase in K/S followed by a decrease in K/S, with dyeing combination 2 showing a decrease in K/S, as the MLR is increased from 1:8 to 1:15 to 1:20. Sequence 2, dyeing combination 1 also shows an increase in K/S followed by a decrease in K/S, with dyeing combination 2 showing a decrease in K/S as the MLR is increased from 1:8 to 1:15 to 1:20.

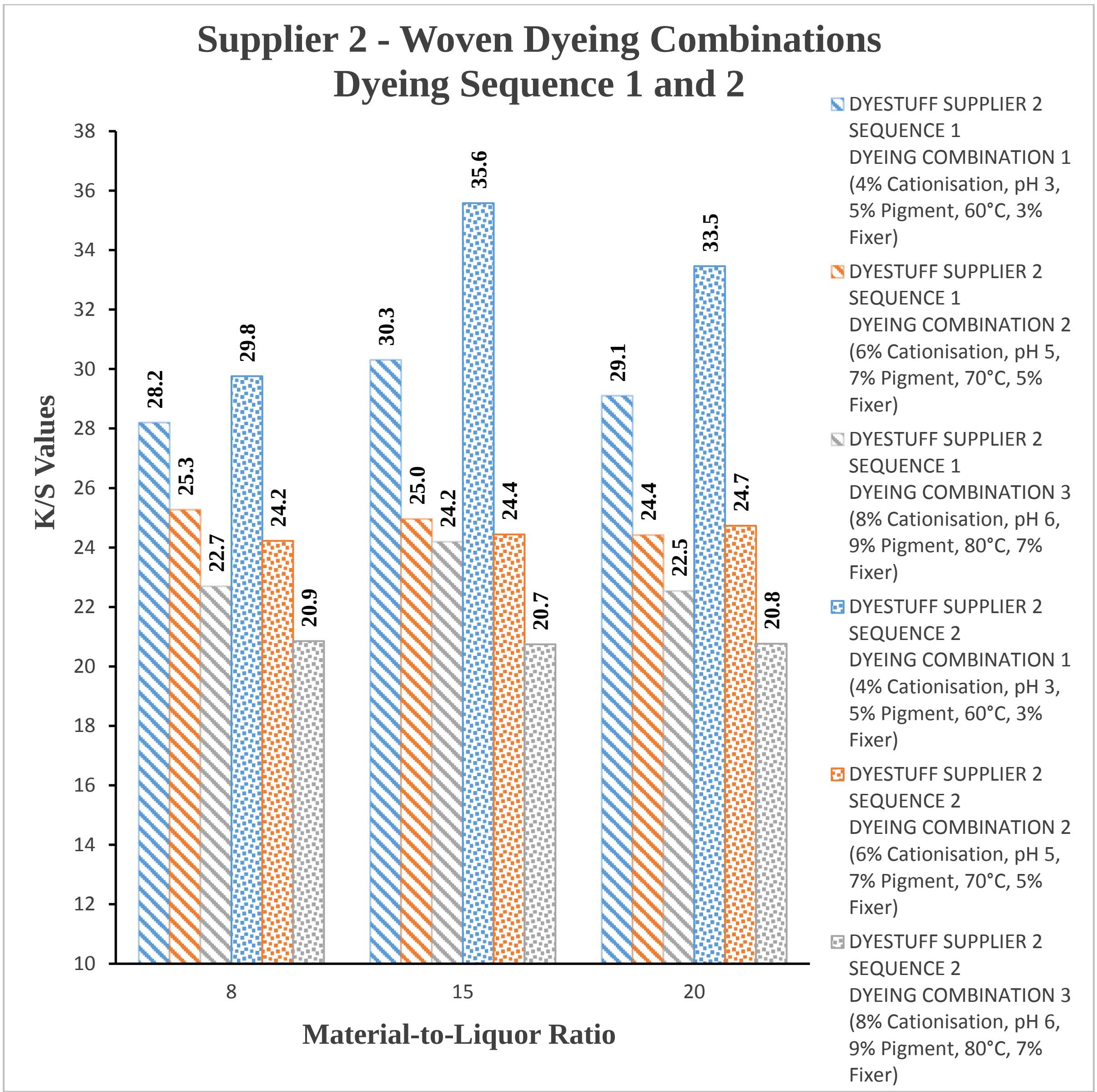


Figure 4.96 Effect of Material-to-Liquor Ratio Level on K/S for the Dyeing Combinations for Woven Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

Table 4.95, shows that sequence 1 achieves the acceptable pass ratings at MLR of 1:15 and 1:20 for dyeing combination 1, and at MLR of 1:20 for dyeing combination 2, as well as at MLR of 1:15 for dyeing combination 3. Sequence 2 obtains the same at all levels of MLR for dyeing combination 1, and at MLR of 1:20 for dyeing combination 2, as well as at MLR of 1:15 for dyeing combination 3. In addition, Figure 4.97 shows the dyeing combinations that have passed in terms of fastness with a rating of 3/4. Accordingly, sequence 2 obtains a pass at all MLR levels, with K/S values slightly higher than that for sequence 1.

Table 4.95 Woven Test Results for MLR Level Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - DYESTUFF SUPPLIER 2																		
MLR Trials:							WOVEN										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	28.2	5	4/5	4/5	5	4/5	3	3	3	2/3	29.2	25.4
	4	3	5	60	3	1:15	30.3	5	5	4/5	5	5	4/5	4	4/5	4		
	4	3	5	60	3	1:20	29.1	5	5	5	5	5	4	4	3/4	3/4		
2	6	5	7	70	5	1:8	25.3	5	4/5	4/5	4/5	4/5	4	3/4	3/4	3	24.9	
	6	5	7	70	5	1:15	25.0	5	4/5	4/5	5	4/5	3	3	4	4		
	6	5	7	70	5	1:20	24.4	5	5	5	4/5	4/5	4	4	4	3/4		
3	8	6	9	80	7	1:8	22.7	5	4/5	4/5	4/5	4/5	3/4	4	3/4	3	23.1	
	8	6	9	80	7	1:15	24.2	5	5	5	5	5	4	4/5	4/5	4		
	8	6	9	80	7	1:20	22.5	5	5	5	5	4/5	3	4	3/4	3		

SEQUENCE 2 - DYESTUFF SUPPLIER 2																		
MLR Trials:							WOVEN										Dyeing Combination Averages	Total MLR Average
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub			
									Face	Back	Face	Back	Face	Back	Face	Back		
1	4	3	5	60	3	1:8	29.8	5	5	5	5	5	4	4	3/4	3/4	32.9	25.6
	4	3	5	60	3	1:15	35.6	5	5	5	5	5	4/5	4/5	4/5	4/5		
	4	3	5	60	3	1:20	33.5	5	5	5	5	5	4	4	4	4		
2	6	5	7	70	5	1:8	24.2	5	5	5	5	5	3/4	3	3	3	24.5	
	6	5	7	70	5	1:15	24.4	5	5	5	5	5	3/4	3	3	4		
	6	5	7	70	5	1:20	24.7	5	5	5	5	5	3/4	3/4	3/4	3/4		
3	8	6	9	80	7	1:8	20.9	4/5	4/5	4/5	5	4/5	3/4	3/4	3	3	20.8	
	8	6	9	80	7	1:15	20.7	5	5	5	5	5	4	4	4	4		
	8	6	9	80	7	1:20	20.8	5	5	5	5	5	3	3	3	2		

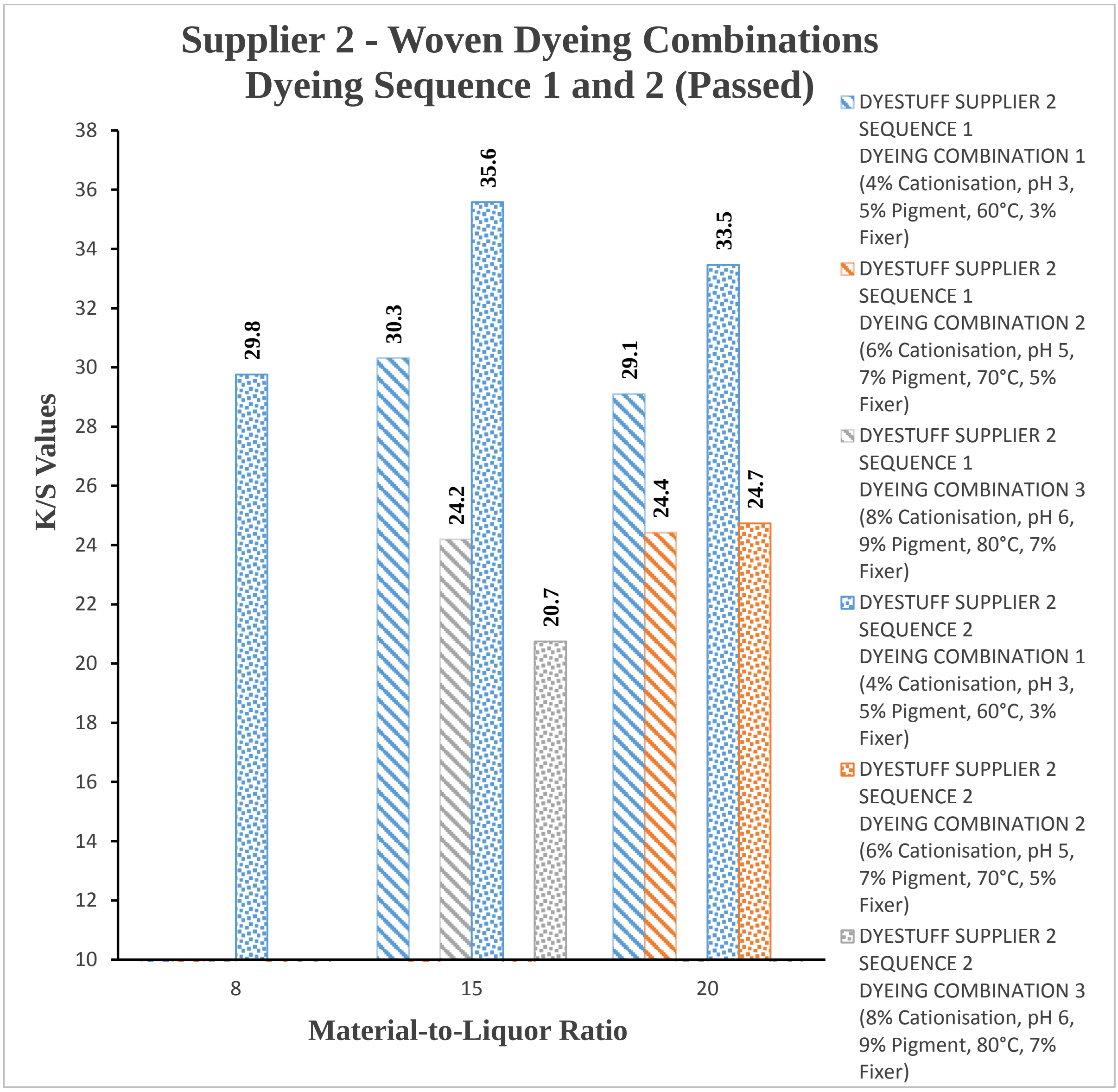


Figure 4.97 Grey Scale Ratings of 3/4 or Higher for Material-to-Liquor Ratio Level Trials for Woven Fabrics for Supplier 2, Dyeing Sequence 1 and 2.

4.3.6.8. DISCUSSION

Acceptable pass ratings of 3/4, as indicated in Figures 4.95 and 4.97, showed that sequence 1 obtained pass ratings at 1:8 and 1:15 MLR for the knitted fabric, while the woven fabric obtained pass ratings at 1:15 and 1:20, whereas sequence 2 obtained pass ratings at all levels of MLR for both fabrics. In addition, 2 dyeing combinations for the knitted, and 5 for the woven, for both sequences, achieved pass ratings of 4 or higher for all fastness. Tables 4.96 and 4.97, represents the dyeing combinations that achieved a Grey Scale rating of 4 or higher, with the ideal choice for knitted being K/S of 30.6 and that of the woven being K/S of 35.6, both at 1:15 MLR for dyeing combination 1, sequence 2, Supplier 2.

Table 4.96 Ideal Dyeing Combinations for Knitted Fabric for MLR Level Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 2																
MLR Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
3	8	6	9	80	7	1:8	19.5	5	5	5	4/5	4/5	4	4	4	4
SEQUENCE 2 - SUPPLIER 2																
MLR Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	3	1:15	30.6	5	5	5	5	5	4/5	4/5	4	4

Table 4.97 Ideal Dyeing Combinations for Woven Fabric for MLR Level Trials for Supplier 2, Dyeing Sequence 1 and 2.

SEQUENCE 1 - SUPPLIER 2																
MLR Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	3	1:15	30.3	5	5	4/5	5	5	4/5	4	4/5	4
3	8	6	9	80	7	1:15	24.2	5	5	5	5	5	4	4/5	4/5	4
SEQUENCE 2 - SUPPLIER 2																
MLR Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	3	1:15	35.6	5	5	5	5	5	4/5	4/5	4/5	4/5
	4	3	5	60	3	1:20	33.5	5	5	5	5	5	4	4	4	4
3	8	6	9	80	7	1:15	20.7	5	5	5	5	5	4	4	4	4

4.3.6.9. CONCLUSION

To conclude the results for all MLR level trials for each supplier and sequence, the average K/S was taken into account. The effect of MLR on K/S, for both knitted and woven fabrics, for both suppliers and sequences showed a decrease in K/S as the MLR levels increased from 1:8 to 1:15 to 1:20 for all dyeing combinations, while the remaining 5 parameters (cationisation, pH, pigment, temperature and binder/fixer) increased in their respective levels.

The knitted and woven fabric for both suppliers achieved a higher average K/S for dyeing sequence 2 compared to that for dyeing sequence 1. Furthermore, both dyeing sequences for Supplier 2, achieved higher average K/S values compared to that for Supplier 1, for both fabrics. In addition, the K/S values for all woven fabric were higher compared to that for the knitted fabric, with the reasons for this difference being explained in section 4.3.7.

Taking the K/S values into account, it can be concluded that the ideal MLR level for the knitted fabric was at 1:15 (K/S of 26.0) for sequence 1 for Supplier 2, while that for the woven fabric was also at 1:15 (K/S of 35.6) for sequence 2 for Supplier 2. In addition, these K/S values also achieved Grey Scale ratings of 4 or higher for all fastness criteria. These ideal MLR levels can neither be confirmed nor supported by previous works carried out, due to investigations only being carried out at MLR of 1:20 by Fang *et al* (2005) and Patra *et al* (2006), however, a lower MLR would reduce processing costs.

4.3.7. Optimum Dyeing Conditions for Knitted and Woven Fabrics

Although ideal dyeing combinations were selected for each parameter investigated, it is essential to choose the optimum dyeing conditions for the knitted and woven fabrics for each sequence, which is summarised in Table 4.98, for Supplier 1 and in Table 4.99, for Supplier 2. From both tables, it can be seen that pass ratings of 4 or higher are achievable for both sequences for Supplier 1, except for the knitted fabric for sequence 2, which achieves the industry pass rate of 3/4 for the wet rub fastness, whereas Supplier 2 achieves pass ratings of 4 or higher for both sequences, with much higher K/S values than those achieved by Supplier 1. The higher K/S achieved by Supplier 2 was indicative of the fixer, which was a melamine-based crosslinking agent of low formaldehyde content, used for improving the fastness of the pigments.

Table 4.98 Optimum Dyeing Conditions for Knitted and Woven Fabrics for Sequence 1 and 2, Supplier 1.

SEQUENCE 1 - SUPPLIER 1																
Temperature Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	70	3	1:8	16.7	4/5	4/5	4/5	4/5	4/5	4	4	4	4
SEQUENCE 1 - SUPPLIER 1																
Cationisation Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	6	3	5	60	3	1:8	20.8	4/5	4/5	4/5	4/5	4/5	4	4/5	4	4
SEQUENCE 2 - SUPPLIER 1																
Binder Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
3	8	6	9	80	3	1:20	12.7	4	4/5	4/5	4/5	4/5	4	3/4	3/4	3/4
SEQUENCE 2 - SUPPLIER 1																
pH Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Binder	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
3	8	3	9	80	7	1:20	21.1	5	4/5	5	5	5	4	4	4/5	4

Table 4.99 Optimum Dyeing Conditions for Knitted and Woven Fabrics for Sequence 1 and 2, Supplier 2.

SEQUENCE 1 - SUPPLIER 2																
MLR Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	3	1:15	26.0	5	5	5	5	5	4	4/5	4/5	4
SEQUENCE 1 - SUPPLIER 2																
Fixer Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	7	1:8	34.0	5	5	5	5	5	4	4	4	4
SEQUENCE 2 - SUPPLIER 2																
MLR Trials:							KNITTED									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	3	1:15	30.6	5	5	5	5	5	4/5	4/5	4	4
SEQUENCE 2 - SUPPLIER 2																
Fixer Trials:							WOVEN									
Dyeing Combination	Cat	pH	Pigment	Temp	Fixer	MLR	K/S (450nm)	Wash Fastness	Warp Dry Rub		Weft Dry Rub		Warp Wet Rub		Weft Wet Rub	
									Face	Back	Face	Back	Face	Back	Face	Back
1	4	3	5	60	7	1:8	36.5	5	5	5	5	5	4/5	4/5	4/5	4

The dyeing trials, for all combinations investigated, concluded that by increasing the levels of each parameter, there was a general decrease in K/S, with sequence 2 achieving a higher K/S for majority of the dyeing trials. The higher K/S values achieved, did however, impact negatively on the general wet rub fastness, as confirmed by Cotton Incorporated (2004), which stated that although this method (sequence 2) produces a uniformly dyed appearance, the dye fastness is decreased. In addition, Broadbent (2001), stated that deep shades have lower fastness to wet treatments and rubbing than pale shades, which was confirmed during this research. Nonetheless, there were exceptions when a high K/S achieved good wet rub fastness of 4 or higher, such as those indicated in Table 4.99, which indicated that the parameters investigated played a vital role in the fastness properties.

It can further be seen that across all the dyeing combinations, the woven fabric for both dyeing sequences achieved a much higher K/S than that of the knitted fabric. A comparison of Figure 3.1 and 3.2, readily suggests that the open-end sample contains both more dyeable substrate per square unit visible area and offers less readily accessible penetration as opposed to the less dense and more absorbent knitted structure. The consequent darker end result of the open-end fabric is observable in these two figures taken under identical lighting, exposure and magnification.

The various levels of the parameters investigated in the trials, influenced the K/S values obtained, with the effects summarised in section 4.3.8 in terms of the average K/S values.

4.3.8. Effect of Parameter Concentrations/Levels on Colour Strength

The knitted and woven fabrics for all dyeing combinations, for both suppliers and sequences, showed a decrease in K/S as each parameter increased in their respective levels.

Knitted Fabric

The knitted fabric, for the cationisation, pH and pigment concentration/level trials, achieved a higher K/S for dyeing sequence 1 for Supplier 1, than that for dyeing sequence 2 for Supplier 1, similarly dyeing sequence 1 for Supplier 2, obtained a higher K/S than that for dyeing sequence 2 for Supplier 2. Whereas the knitted fabric, for temperature, binder/fixer and MLR concentration/level trials, achieved a higher K/S for dyeing sequence 2 for Supplier 1, than that for dyeing sequence 1 for Supplier 1, similarly dyeing sequence 2 for Supplier 2, obtained a higher K/S than that for dyeing sequence 1 for Supplier 2.

Woven Fabric

The woven fabric, for all parameters, achieved a higher K/S for dyeing sequence 2 for Supplier 1, than that for dyeing sequence 1 for Supplier 1, similarly dyeing sequence 2 for Supplier 2, obtained a higher K/S than that for dyeing sequence 1 for Supplier 2. Whereas for the knitted and woven fabrics, both dyeing sequences, for Supplier 2, achieved higher K/S values than that for Supplier 1. The K/S values for all dyeings for the woven fabric is higher than that for the knitted fabric.

Chapter 5: Conclusions and Recommendations

5.1. CONCLUSION

The exhaust pigment dyeing of cotton garments has not received much acceptance, mainly due to the problems associated with unevenness and poor wet fastness to rubbing. In an aim to improve the above mentioned problems, as well as reduce processing costs and aiming towards a greener textile industry, this research investigated the exhaust pigment dyeing of woven and weft knitted cotton garments by varying 6 parameters at 3 levels each. The effects of varying the 6 parameters, namely Cationization, pH, Pigment, Binder/Fixer, Temperature and MLR, together with a change in the process route, were systematically investigated to determine their influence on colour strength, wash fastness and colour fastness to rubbing on woven and knitted exhaust pigment dyed cotton garments.

It was found that all the dyeings conducted during this research achieved acceptable levelness due to the pigment being added over periodic intervals instead of all at once. During the initial stages of dyeing, the rotary drum machine did not stain adversely, however, after about 20 dyeings, staining of the machine became evident, which became increasingly worse due to the large number of samples dyed for this research (156 dyeings). Nevertheless, the results for wash fastness and change in colour, for all parameters, and for all dyeing combinations, for both suppliers, obtained industry pass ratings of 4 or higher. Although acceptable industry pass ratings of 3/4 for wet rub fastness were achieved for all parameters, across certain dyeing combinations, this research concluded that ratings of 4 or higher were possible under certain dyeing conditions, thus encouraging industry to use pigment dyeing of cotton garments. Table 5.1 summarises the optimum levels for each parameter, which achieved the highest K/S together with fastness rating of 4 and higher for the wet rub fastness. The table further shows that both sequences, for supplier 2, requires the same levels for each parameter, differing only in Binder/Fixer and MLR for both the knitted and woven fabrics.

Table 5. 1. Optimum Levels for each Parameter.

Optimum Levels for each Parameter		
Parameters	**Sequence 1 and 2 - Supplier 2**	
	Knitted	**Woven**
Cationisation	4%	4%
pH	3	3
Pigment	5%	5%
Temperature	60°C	60°C
Fixer	3%	7%
MLR	1:15	1:8

It can therefore be concluded that the above dyeing conditions will achieve highly acceptable pigment levelness, fastness and colour strength, making the exhaust pigment dyeing of knitted and woven cotton garments attractive as a more economical method of dyeing in terms of shorter processing times and reduced impact on the environment, due to reduced chemical use.

5.2. RECOMMENDATIONS

Preliminary sample dyeing trials on pigments and auxiliaries need to be conducted prior to purchase since their chemical constitution would differ from those used in this research, therefore leading to a difference in results as those obtained herin. In addition, it would be preferable to conduct these sample dyeing trials on the same quality of knitted and woven fabrics in terms of fibre and yarn type and construction, to gauge a clear outcome on the results obtained when various parameters are changed.

5.3. FUTURE WORKS

Pigment dyeing still poses a problem in terms of staining of the dyeing equipment, with future work investigating a means of reducing the amount of staining of the dyeing equipment. Other pigment colours, including mixtures, could also be investigated as this research was only concerned with Blue pigments. In addition to this, since only a partial factorial was done, further work could focus on a full factorial which would enable statistical analyses to be conducted, thereby leading to better interpretation of the results and in so doing, obtain a model for the textile industry to utilize.

REFERENCES

Adanur, S. 2001. *Handbook of Weaving*. Switzerland: Sulzer Textil Limited.

Ajgaonkar, S.B. 1993. Garment Dyeing: Pros and Cons. *Colourage*. 7: 21-24.

American Association of Textile Chemists and Colorists Technical Manual. 2005. Vol.81. North Carolina: AATCC.

Aspland, J. R. 1997. *Textile Dyeing and Coloration*. North Carolina.: American Association of Textile Chemists and Colorists. p.410.

Astruc, L. 2011. *The Cotton Trade Global Yarn* (online). Available: http://www.befair.be/sites/default/files/all-files/brochure/Brochure%20coton-EN-BD.pdf. (Accessed 12 August 2017).

Balasubramanian, N. 2013. Rotor Spinning: Effect of Rotor, Navel Parameters, Winding Tension. Indian Textile Journal. 123(10): 29.

Bamfield, P. 2001. *Chromic Phenomena: The Technological Applications of Colour Chemistry*. Cambridge: The Royal Society of Chemistry.

Buxbaum, G. 1993. *Industrial Inorganic Pigments*. Weinheim: VCH.

Behera, B. K., Militky, J., Mishra, R. and Kremenakova, D. 2012. *Modeling of Woven Fabrics Geometry and Properties* (online). Available: http://www.intechopen.com/books/woven-fabrics/modeling-of-woven-fabrics-geometry-and-properties. (Accessed 05 January 2017).

Bellini, P., Bonetti, F., Franzetti, E., Rosace, G., Vago, S. 2001. *Finishing Reference Books of Textile Technologies*. Milan: ACIMIT.

Binders for Textile Applications. 2004. Technical Bulletin. Cotton Incorporated. ISP (1008): 1-16.

Blanchard, E.J., Harper, R.J., Allen, H.A. 1988. Dyeability of crosslinked cationic cotton. *Textile Chemist and Colorist*. 20(1): 25-35.

Bone. J. A., Collishaw, P. S., and Kelly, T. D. 1988. Garment Dyeing. *Review of Progress in Coloration and Related Topics*. 18: 37-46.

Broadbent, A.D. 2001. *Basic Principles of Textile Colouration*. Bradford: Society of Dyers and Colourists.

Burkinshaw, S.M., Mignanelli, M., Froehling, P.E., and Bide, M.J. 2000. The use of dendrimers in modifying the dyeing behavior of reactive dyes of cotton. *Dyes and Pigments*. 47: 259-267.

Canal, J.M., Rodriguez, C., Caballero, G., Julia, M.R. 1998. Chitosan Boosts Dyeing Efficiency. *International Dyer*. 183(2): 16-24.

Cao, Q. 2013. *An Investigation into the Development of Environmentally Friendly Pigment Colouration*. PhD Thesis. Manchester: School of Materials.

Carr, C.M. 1995. *Chemistry of the textiles industry*. Cambridge: Chapman.

Cawood, G., and Scotney, J. 2000. Current Trends in Garment Processing. *Review of Progress in Coloration and Related Topics*. 30: 35-40.

Chakraborty, J. N. 2014. *Fundamentals and Practices in Colouration of Textiles*. 2nd Ed. New Delhi: Woodhead Publishing India Pvt Ltd.

Chakraborty, J. N., Pal, R., and Megha, P. R. 2005. Garment Dyeing. *Indian Journal of Fibre and Textile Research*. 30: 468-476.

Chavan, R. B. 1981. *Proceedings, Seminar on Rotor Spinning*. Indian Institute of Technology, Delhi. 122.

Chottopadhyay, D.P. 2001. Cationization of Cotton for low-salt or salt-free dyeing. *Indian Journal of Fibre and Textile Research*. 26: 108-115.

Choudhury, A.K. 2014. Coloration of Cationized Cellulosic Fibers – A Review. *AATCC Journal of Science*. 1(3): 11-19.

Christie, R.M., Mather, R.R., Wardman, R.H. 2000. *The Chemistry of Colour Application*. Oxford: Blackwell Science Ltd.

Clark, M. 2011. *Handbook of Textile and Industrial Dyeing: Vol. 1: Principles, processes and types of dyes*. Cambridge: Woodhead Publishing Limited.

Colour Fastness to Domestic Washing Procedures. 2006. South African National Standards. Pretoria: Standards South Africa.

Colour Fastness to Rubbing – C8. 2004. Marks and Spencer.

Colour Index. 1971. 3rd Ed. Vol. 1-5. Bradford: Society of Dyers and Colourists, and North Carolina: American Association of Textile Chemists and Colorists.

Cotton South Africa. 2016. Cotton SA Market Report (online). Available: http://www.cottonsa.org.za. (Accessed 26 September 2016).

Dawson, T. 2011. Progress towards a Greener Textile Industry. *Coloration Technology*. 128: 1-8.

Denton, M. J., and Daniels, P. N. 2002. *Textile Terms and Definition*. 11th ed. Manchester: Textile Institute.

Department of Agriculture, Forestry and Fisheries (RSA). 2016. *A Profile of the South African Cotton Market Value Chain 2015* (online). Available: http://www.daff.gov.za. (Accessed 03 January 2016).

Ethridge, D. 2016. Policy-Driven Causes for Cotton's Decreasing Market Share of Fibres. *33rd International Cotton Conference*. Bremen: March 16 – 18.

Evans, G.E., Shore, J., and Stead, C.V. 1984. Dyeing Behaviour of Cotton after Pretreatment with Reactive Quaternary Compounds. *Journal of Society of Dyers and Colourists*. 100(10): 304-315.

Fang, K.J. 2010. Pigment Dyeing of Polyamide-Epichlorohydrin Cationized Cotton Fabrics. *Journal of Applied Polymer Science*. 118(5): 2736-2742.

Fang, K., Wang, C., Zhang, X., and Xu, Y. 2005. Dyeing of Cationised Cotton using Nanoscale Pigment Dispersions. *Coloration Technology*. 121: 325-328.

Fairchild, M. D. 2005. *Color Appearance Models*. 2nd Ed. West Sussex: John Wiley and Sons Ltd.

Garment Dyeing with Pigments. 2000. Technical Bulletin. Cotton Incorporated.

Global Fibre Market. 2016. Lenzing Group (online). Available: www.lenzing.com/en/investors/equity-story/global-fiber-market.html. (Accessed 22 March 2017).

Gokarneshan, N. 2004. *Fabric Structure and Design*. New Delhi: New Age International (Pty) Ltd.

Gordon, S., and Hsieh, Y. L. 2007. *Cotton: Science and Technology*. Cambridge: Woodhead Publishing Limited.

Greaves, P. H., Saville, B. P., and Royal Microscopial Society (Great Britain). 1995. *Microscopy of Textile Fibres*. Oxford: BIOS Scientific in association with the Royal Microscopial Society.

Guo, G.Y. and Chen, Y.L. 1994. *American Dyestuff Reporter*. 83(9): 58.

Hammonds, A.G. 1995. Introduction to Binders. *Pigment Printing Handbook*. North Carolina: American Association of Textile Chemists and Colorists.

Hao, Z. M. and Iqbal, A. 1997. Some Aspects of Organic Pigments. *Chemical Society Reviews*. 26(3): 203-213.

Hari, P. K., and Shankaranarayanan, G. 1984. Comparison of Physical and Mechanical Properties of Ring and Rotor Yarn Fabrics. *Indian Journal of Textile Research*. 9: 85 – 89.

Hauser, P.J., and Pslopek, R. 2005. *Colourage*. September.

Herbst, W. and Hunger, K. 2004. *Industrial Organic Pigments*. 3rd Ed. Wiley-VCH Verlag GmbH and Co: Weinham.

Hu, J. 2004. *Structure and Mechanics of Woven Fabrics*. Cambridge: Woodhead Publishing Limited in association with The Textile Institute.

Hunger, K. 2003. *Industrial Dyes: Chemistry, Properties, Application*. Germany: WILEY-VCH Verlag GmbH & Co. KGaA.

Holme, I. 1992. Market Development: Challenge to Dyeing and Finishing. *Review of Progress in Coloration and Related Topics*. 22: 1-13.

Ingamells, W. 1993. *Colour for Textiles: A User's Handbook*. Bradford: Society of Dyers and Colourists.

Iyer, V., and Shenai, V. A. 1991. Dyeing Behaviour of Open-End and Ring-Spun Cotton Yarns. *Indian Journal of Fibre and Textile Research*. 16: 236 – 238.

Johnson, A. E. 1989. *The Theory of Coloration of Textiles*. 2nd ed. Bradford: Society of Dyers and Colourists.

Jaeckel, S. M. 1980. Variability of Grey-Scale Assessment and its Contribution to the Variability of a Test Method. *Journal of the Society of Dyers and Colourists*. 96(10). 540-544.

Karmakar, S.R. 1999. *Chemical technology in the pre-treatment processes of textiles*. Amsterdam: Elsevier Science B.V. Hall.

Karypidis, M.I. 2000. *Effect of Softening Agents on the Wear of Textiles*. 2000. PhD Thesis. Manchester: UMIST.

Kass, M. 1958. Possibilities and Limitations of the Application of Pigment to Textiles. *Journal of Society of Dyers and Colourists*. 74(1): 74-75, 95.

Kin, T.K., Yoon, S.H., and Son, Y.A. 2004. Effect of reactive anionic agent on dyeing of cellulose fibres with a berbine colorant. *Dyes and Pigments*. 60: 121-127.

Klemm, D., Philipp, B., Heinze, T., Heinze, U., and Wagenknecht, W. 1998. *Comprehensive Cellulose Chemistry, Volume 1: Fundamentals and Analytical Methods*. Weinham: Wiley-VCH Verlag GmbH.

Kuehni, R.G. 2005. *Color: An Introduction to Practice and Principles*. 2nd Ed. New Jersey: John Wiley and Sons Inc.

Kumar, M., Dr. Chinta, S.K., and Kumar, D. 2013. Adsorption and Thermodynamic Study of Pigment Dyeing on Cationised Cotton. *International Journal of Fibre and Textile Research*. 3(1): 6-12.

Lacasse, K. and Baumann, W. 2004. *Textile Chemicals: Environmental Data and Facts*. London: Springer.

Lever, T. 1992. Exhaust Dyeing with Pigments on Cotton Piece and Garments. *Journal of Society of Dyers and Colourists*. 108(11): 477-478.

Lewin, M. 2006. *Cotton Fiber Chemistry and Technology*. Boca Raton: CRC Press Taylor and Francis Group.

Lewis, D. M. 1999. Coloration in the Next Century. *Review of Progress in Coloration and Related Topics*. 29: 23-28.

Lewis, D.M. and Lei, X.P. 1991. New Methods of Improving the Dyeability of Cellulose Fibres with Reactive Dyes. *Journal of Society of Dyers and Colourists*. 107(3): 102-109.

Lewis, D. M., and McIlroy, K. A. 1997. The Chemical Modification of Cellulosic Fibres to Enhance Dyeability. *Review of Progress in Coloration and Related Topics*. 27: 5-17.

Lord, E. 1961. *Manual of Cotton Spinning. Vol. II Part I. The Characteristics of Raw Cotton.* Manchester and London: Butterworth and Company (Ltd) and the Textile Institute.

Love, U. P. G. 1999. *Scanning Electron Microscopy*, in Centre for Electron Optical Studies. United Kingdom: University of Bath.

Madaras, G.W., Parish, G. J., and Shore, J. 1993. *Batchwise Dyeing of Woven Cellulosic Fabrics: A Practical Guide*. Bradford: Society of Dyers and Colourists.

Marsh, J. T. 1948. *Textile Science: An Introductory Manual*. London: Chapman and Hall Ltd.

Mazza, C., and Paola, Z. 2001. *Reference Books of Textile Technologies: Knitting*. Italy: ACIMIT Fondazione.

McDonald, R. 1997. *Colour Physics for Industry*. 2nd Ed. Bradford: Society of Dyers and Colourists.

Miles, L.C.W. 2003. *Textile Printing*. Rev. 2nd Ed. Bradford: Society of Dyers and Colourists.

Nakpathom, M., and Phromphen, P. 2008. Natural lac dyeing of cotton and silk fabrics pretreated with CHTAC. *Technology and Innovation for Sustainable Development Conference*. January.

Nassau, K. 1998. *Color for Science, Art and Technology*. Amsterdam: Elsevier Science B. V.

Nettles, J.E. 1983. *Handbook of Chemical Specialities: Textile Fibre Processing, Preparation, and Bleaching*. New York: Wiley.

Ohta, N., and Robertson, A.R. 2005. *Colorimetry: Fundamentals and Applications*. West Sussex: John Wiley and Sons Ltd.

Park, J. 1993. *Instrumental Colour Formulation: A practical guide*. Bradford: Society of Dyers and Colourists.

Park, J. and Shore, J. 2004. *Practical Dyeing*. Vol. 3. Bradford: Society of Dyers and Colourists.

Patra, A.K., Bhaumik, S., Kaur, H. 2006. Studies on Pigment dyeing of Cotton by Exhaust Method. *Indian Journal of Fibre and Textile Research*. September. 31: 450-459.

Patton, T.C. 1973. *Pigment Handbook*. New York: Wiley.

Rafique, S., Parveen, S., Ahmad, B., Hussain, T. 2014. Pigment Dyeing and Finishing of Cotton/Polyester Fabrics with a Modified Dihydroxyehtyleneurea and Various Softeners. *Life Science Journal*. 11(5): 165-174.

Ristić, N. and Ristić, I. 2012. Cationic Modification of Cotton Fabrics and Reactive Dyeing Characteristics. *Journal of Engineered Fibers and Fabrics*. 7(4): 113-121.

Saha, T. and Dina, R.B. 2015. A study on garments dyeing with direct dyes and pigments in Bangladesh. *International Journal of Scientific Engineering and Technology*. 4(8): 423-425.

Saravanan, D., and Ramachandran, T. 2008. Comprehensive View on Garment Dyeing and Finishing. *IE(I) Journal-TX*. August. 89: 14-19.

Saville, B. P. 1999. *Physical Testing of Textiles*. Cambridge: Woodhead Publishing.

Schindler, W.D. and Hauser, P.J. 2004. *Chemical Finishing of Textiles*. Cambridge: Woodhead Publishing Ltd.

Schwarz, S. and Endriss, H. 1995. Inorganic Colour Pigments and Effect Pigments Technical and Environmental Aspects. *Review of Progress in Coloration and Related Topics*. 25(1): 6-17.

Schwindt, W. and Faulhaber, G. 1984. The Development of Pigment Printing Over the Last 50 Years. *Review of Progress in Coloration and Related Topics*. 14(1): 166-175.

Scotney, J. 1989. The Scope of Garment-Dyeing. *Textile Progress*. 19(2): 29-32.

Sharma, M., and Nachane, R. P. 2010. A Novel Method for Scouring Textile Cotton. *Indian Journal of Fibre and Textile Research*. 35: 72-74.

Shenai, V.A. 1993. *Technology of Textile Processing*. Vol. 2. Mumbai: Sevak Publication.

Shore, J. 1995. *Cellulosics Dyeing*. Bradford: Society of Dyers and Colourists.

Shore, J. 2002. *Colorants and Auxiliaries*. Vol. 1 and 2. 2nd ed. Bradford: Society of Dyers and Colourists.

Smith, P. J. 1994. Colour Fastness Testing Methods and Equipment. *Review of Progress in Coloration and Related Topics*. 24: 31-38.

Spencer, D. J. 2001. *Knitting Technology: A Comprehensive Handbook and Practical Guide*. 3rd ed. Cambridge: Woodhead Publishing Limited.

Stan-Kleinschek, K., and Ribitsch, V. 1998. Electrokinetic properties of processed cellulose fibres. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 40: 127-138.

Tayyebkhan, A. 1996. *Colour Physics*. Oil and Colour Chemists Association.

Teli, M.D. 1996. New Developments in Dyeing Process Control. *Indian Journal of Fibre and Textile Research*. 21: 41-49.

The Resilient: A customer interface from Resil Chemicals. 2007. 7(2): 10-21.

Thompson, D. 1995. Pigment Printing Auxiliaries. *Pigment Printing Handbook*. North Carolina: American Association of Textile Chemists and Colorists.

Völz, H.G. 2002. Industrial Color Testing: Fundamentals and Techniques. 2nd Ed. Wiley-VCH Verlag GmbH and Co: Weinham.

Wang, C. and Yin, Y. 2013. Preparation, Characterization and Application of Ultra-Fine Modified Pigment in Textile Dyeing (online). Available: http://dx.doi.org/10.5772/53489. (Accessed 24 December 2015).

Wang, L.L. 2009. Preparation of Cationic Cotton with Two-bath Pad-bake Process and its Application in Salt-free Dyeing. *Carbohydrate Polymers*. 78(3): 602-608.

Wei, Q. 2009. *Surface Modification of Textiles*. Cambridge: Woodhead Publishers Ltd.

Whistenant, J. 1995. Pigments in Textile Printing. *Pigment Printing Handbook*. North Carolina: American Association of Textile Chemists and Colorists.

Wilson, J. 2000. *Handbook of Textile Design: Principles, Processes and Practice*. Cambridge: Woodhead Publishing Limited.

Wu, T.S., and Chen, K.M. 1992. New cationic agents for improving the dyeability of cellulose fibres. Part 1- Pretreating cotton with Polyepichlorohydrin–Amine Polymers for improving dyeability with direct dyes. *Journal of Society of Dyers and Colourists*. 108: 388-394.

Wu, T.S., and Chen, K.M. 1993. New cationic agents for improving the dyeability of cellulose fibres. Part 2- Pretreating cotton with Polyepichlorohydrin–Amine Polymers for improving dyeability with reactive dyes. *Journal of Society of Dyers and Colourists*. 109: 153-158.

Wu, Y., and Zhang, Z. 2013. Application of Cationic Modification Agent to Pigment Dyeing. *Advanced Materials Research*. 627: 369-373.

Youssef, Y.A. 2000. Direct Dyeing of Cotton Fabrics Pre-treated with Cationising Agents. *Journal of Society of Dyers and Colourists*. 116(10): 316-322.

Zollinger, H. 1991. *Color Chemistry: Syntheses, Properties, and Applications of Organic Dyes and Pigments*. 2nd rev. edn. Weinheim: Cambridge: VCH. xvi: 496.