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RESEARCH ARTICLE

Testing budget photosystems to reach an optimal solution for the herbarium digitization purposes

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Abstract

The current paper stresses the application of different budget photosystems for digitization of herbarium specimens. Twelve photosystems were compared by color accuracy reproduction of the images. It was found that the photosystem built on the basis of photocamera Canon EOS 800D and fixed lens Tokina AT-X M35 PRO DX AF 35 mm f/2.8 Macro and currently used for the digitization of the LWS herbarium collection demonstrated the best results among other tested photosystems. It also produced the images with the same or even better color accuracy as in images downloaded from P, PI, B, and W virtual herbaria. Nevertheless, its color accuracy measured as ΔE_{2000}, in general, does not meet recent criteria ascertained for the herbarium digitization purposes and new FADGI's requirements. This photosystem has been found to have improving potential and, hence, should be optimized. On the other hand, it was also shown that smartphone Samsung Galaxy S10 could produce images with the same or even better color accuracy compared to some images deposited at P, PI, W, and B virtual herbaria. Therefore, in conditions of extreme situations and hostilities, such smartphones with additional external illumination can serve for urgent digitization of natural history collections. Finally, we doubt the application of commonly used color targets for the digitization of herbariaum preserved specimens since the original living color of such specimens is usually lost during conservation and preservation. Instead, it would be more beneficial to apply advanced targets to evaluate the spatial accuracy of images since they can incorrectly represent the important morphological characters of preserved specimens.

Keywords: herbarium digitization, image quality assessment, photosystems, delta E, color accuracy

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Introduction

The digitization of natural history collections has attracted the attention of many recent specialists (Nelson & Ellis, 2019; Hedrick et al., 2020; Hussein et al., 2022). At its best, it grants free, fast, and easy access to deposited specimens through databases and virtual collections (Drew et al., 2017; Schindel & Cook, 2018; Jackowiak et al., 2022). Such virtual collections do not fully substitute original deposited material but significantly extend its application in research (Gries et al., 2014; Khan et al., 2021; Davis, 2023), including extensive biodiversity-related meta-analyses (Dawson-Glass & Hargreaves, 2022; Carta et al., 2022; Samain et al., 2023) and, in some sense, secure its long-term virtual preservation (Novikov, 2019). Such virtual backup of the natural history collections in Ukraine became a crucial task in light of the negative effect of hostilities and related factors, e.g., the inability to warrant stable preservation conditions due to blackouts or lack of personnel (Vajda et al., 2022; Novikov et al., 2023). Being at risk of direct attack or air strike, every natural history collection in Ukraine is insecure and can be damaged (Mosyakin & Shiyan, 2022) or destroyed (Pavlyshyn, 2022; Le Page, 2022).

Image quality assessment is one of the steps in the digitization workflow (Nieva de la Hidalga et al., 2020). The quality of obtained digital images can be evaluated based on numerous parameters, including colorimetric ones. Among them, color reproduction quality is an important parameter that is considered during the digitization of natural history collections (Hasler & Suesstrunk, 2003; Zerman et al., 2019). It is usually quantified as ΔE (delta E) – the difference between the actual color of the object and the color reproduced on the image (Hasler & Suesstrunk, 2003; Palus, 2006; Gu et al., 2022). The smallest ΔE conforms to the best reproduction of the color. The acceptable ΔE value is regulated by two leading legal authorities, i.e., Metamorfoze (the Dutch National Programme for the Preservation of Paper Heritage) and FADGI (the Federal Agencies Digitization Guidelines Initiative, USA). Among other image parameters (colorimetric and representing spatial accuracy), Metamorfoze (van Dormolen, 2012, 2019) calculates ΔE using the technical test chart Digital ColorChecker SG with an old CIE 1976 formulae (ΔE_{1976}). In the recent FADGI guide (Rieger et al., 2023), the calculation of ΔE follows ISO 13658:2000 standard (ΔE_{2000}). The application of different formulae makes these two standards incomparable directly but allows ascertaining some parallels. Metamorfoze has three levels of image quality (from low to high) based on complex calculations, i.e., Extra Light, Light, and Strict. Similarly to Metamorfoze, FADGI delimits four grades of digital image quality. The lowest FADGI's one-star level has no equivalent level in Metamorfoze, while the next two- to four-star levels more or less correspond to Extra Light, Light, and Strict Metamorfoze levels, respectively (DT Heritage, 2023).

Neither Metamorfoze nor FADGI regulate the digitization of natural history collections directly but provide general requirements for digital images of the heritage. FADGI (Rieger, 2016; Rieger et al., 2023) subdivides the digitized materials into several types, and each type has its own four levels of quality with ascertained requirements, including acceptable ΔE color accuracy level. Following the recently published FADGI guide (Rieger et al., 2023), the digitization of herbarium collections, for example, falls under the definition "Documents (Unbound): General Collections". Meanwhile, in Metamorfoze (van Dormolen, 2012), there is no initial subdivision of digitized materials by type, and only three levels of quality are ascertained with the indication of materials for digitization of which they are applied. Hence, the digitization of herbarium collections best fits the Metamorfoze Light level.

The Metamorfoze, in a strict sense (van Dormolen, 2012), requires the average ΔE_{1976} for digital images to be ≤4 while the maximum ΔE_{1976} should not exceed 10 (van Dormolen, 2012). However, there is also a Metamorfoze Light and Metamorfoze Extra Light levels, which require average $\Delta E_{1976} \leq 5$ and maximum $\Delta E_{1976} \leq 18$. In FADGI (Rieger et al., 2023), the lowest ΔE_{2000} (one-star quality level) should not exceed 6.5, and the maximum ΔE should not exceed 13. For FADGI's highest quality, four-star level, the average ΔE_{2000} should not exceed 2, and the maximum ΔE_{2000} should not exceed 4. Considering FADGI's standard, Nieva de la Hidalga et al. (2020) suggested that for the herbarium material, the minimal acceptable ΔE_{2000} value of images should be < 5.

This study aimed to stress the color quality of images obtained using the photosystem built combining cropped photocamera Canon EOS 800D and fixed lens Tokina AT-X M35 PRO DX AF 35 mm f/2.8 Macro. This photosystem is currently used for digitization of the herbarium of vascular plants at the State Museum of Natural History of the NAS of Ukraine (LWS) and is described in detail by Novikov & Sup-Novikova (2021).

Material and methods

We tested 12 camera/lens combinations of different classes (Table 1) placed on the horizontal tripod Beike Q999H with two LED lamps Yongnuo YN-300 Air at the same illumination conditions. For all cameras, the same or closest possible presets were applied, including light sensitivity ISO 200, diaphragm f/5.6, and exposition 1/50 s. The ColorChecker Classic Mini, regularly used for image capturing during the herbarium digitization, has been applied as a test target. Obtained images in jpeg format were not objected for any postprocessing and analyzed as is. For this purpose, their ΔE_{1976} and ΔE_{2000} values were calculated using delt.ae free web application (Picturae, 2023).

We also compared the ΔE_{2000} of the images captured by the LWS's regular photosystem (i.e., Canon EOS 800D with Tokina AT-X M35 PRO DX AF 35 mm f/2.8 Macro) with those for images obtained from ten virtual herbaria, namely BR (jpeg), L (jpeg), P (jpeg), B (jpeg), US (jpeg), NY (jpeg), W (tiff), BM (tiff and jpeg), GZU (tiff), and PI (tiff). The acronyms of represented herbaria follow Thiers (2023). In particular, 30 randomly selected images were downloaded from each mentioned digital herbaria in the highest available resolution and processed through the delt.ae free web application (Picturae, 2023). The images from BM herbarium were downloaded both in jpeg and tiff formats. Thus, including LWS, 360 images were analyzed in total. After that, outliers were excluded from the analyses and substituted by additionally downloaded images. Minimum, maximum, and mean values, as well as standard deviation (SD) for obtained ΔE_{2000} were calculated, and graphs were visualized using PAST ver. 4.14 software (Hammer et al., 2001).

Results and discussion

Among all tested camera/lens combinations, the photosystem currently applied at the LWS herbarium demonstrated the best result and was the only producing part of images meeting Nieva de la Hidalga et al. (2020) criteria. Following the recently published FADGI guide (Rieger et al., 2023), LWS's photosystem received only two stars among four. However, after the exclusion of outliers, the LWS's photosystem demonstrated only 7.7 mean value of ΔE_{2000}, and hence did not pass FADGI (Rieger et al., 2023) and Nieva de la Hidalga et al. (2020) requirements (Table 1).

Besides this, only the full-frame Sony α7 II with lens FE 28-70 mm 3.5-5.6 OSS passed the new FADGI requirements (Rieger et al., 2023) and received one star without processing images through CameraRAW app. Not all other tested photosystems passed the FADGI requirements on minimal acceptable value of ΔE_{2000}. Following the currently applied Metamorfoze guide (van Dormolen, 2012), none of the tested photosystems meet minimal ΔE_{1976} value requirements (Table 1).

Interestingly, the inbuilt camera of the old smartphone Samsung Galaxy S10 camera demonstrated better color accuracy than some cameras with stock or integrated lenses (Table 1). However, it should be taken into account that images produced by smartphones are processed through the original firmware and different apps. As a result, the quality of obtained images can differ even between the same models of smartphones using different versions of the firmware or different apps. To avoid serious modification of the images by the original firmware of the smartphone, it is recommended to use the Open Camera app.

It is also interesting that Canon EOS 800D with a cropped matrix but with a high-end macro lens from Tokina demonstrated better color accuracy than the full-frame camera Sony α7 II with a stock lens. Hence, the crop factor is not limiting here, and the primary attention in the photosystem construction for digitization purposes should be paid to the lens quality.

The same cameras with different lenses demonstrated quite different ΔE outcomes

Table 1. The best values of ΔE_{2000} obtained using different testing photosystems.

Camera and lens specs	Canon Power Shot SX10IS with IS 5-100 mm 1:2.8-5.7 USM	Nikon 1 V1 with Nikkor 10-30 mm 1:3.5-5.6 VR	Canon Rebel T7i (EOS 800D) with Canon EF 50 mm f/1.4 USM	Canon Rebel T4i (EOS 650D) with EFS 18-55 mm 3.5-5.6 IS STM	Canon Rebel T4i (EOS 650D) with EFS 18-135 mm 1:3.5-5.6 IS USM	Samsung EX2F with Schneider-Kreuznach Varioplan Zoom 5.2-17.2 mm 1:1.4-2.7 Duals
Camera class	Old tele-zoom camera	Old mirrorless camera	Recent cropped camera	Old cropped camera	Old cropped camera	Old extra-bright pocket camera
Color reproduction accuracy from low to high →						
Sensor type	CCD	CMOS	CMOS	CMOS	CMOS	BSI CMOS
Sensor size	1/2.3" (6.17 × 4.55 mm)	1" (13.2 × 8.8 mm)	APS-C (22.3 × 14.9 mm)	APS-C (22.3 × 14.9 mm)	APS-C (22.3 × 14.9 mm)	1/1.7" (7.6 × 5.7 mm)
Resolution	10 Mp	10 Mp	24.2	18 Mp	18 Mp	12.4 Mp
Best $\mu\Delta E_{2000}$	14.3	10.8	10.4	9.7	9.7	9.2
Best $\mu\Delta E_{1976}$	18.3	22.5	13.9	20.8	13.8	12.4
Delt.ae Color Encoding Error (ΔE_{2000})	*	*	*	*	*	*
FADGI Ed. 2 (Rieger, 2016)	–	–	*	*	*	*
FADGI Ed. 3 (Rieger et al., 2023)	–	–	–	–	–	–
Metamorfoze (van Dormolen, 2012)	–	–	–	–	–	–
Acceptable level for the herbarium digitization (Nieva de la Hidalga et al., 2020)	No	No	No	No	No	No

Table 1. Continued.

Camera and lens specs	Samsung Galaxy S10	Panasonic Lumix DC-G9 with Sigma 30 mm f/1.4 DC DN Contemporary (regular mode)	Nikon D90 with Nikkor DX AF-S 18-105 mm 1:3.5-5.6 G ED	Canon Rebel T7i (EOS 800D) with Canon EF 100 mm f/2,8L Macro IS USM	Sony Alpha ILCE-α7 II with FE 28-70 mm 3.5-5.6 OSS (ILCE-7M2)	Panasonic Lumix DC-G9 with Sigma 30 mm f/1.4 DC DN Contemporary (pixel-shift mode)	Canon Rebel T7i (EOS 800D) with Tokina Macro 35 F2.8 mm DX AT-X Pro
Camera class	Smartphone	Recent mirrorless camera	Old cropped camera	Recent cropped camera	Full-frame camera	Recent mirrorless camera	Recent cropped camera
Color reproduction accuracy from low to high →							
Sensor type	ISOCELL CMOS	CMOS	CMOS	CMOS	CMOS	CMOS	CMOS
Sensor size	SAK2L4 1/2.55" (5.6 × 4.2 mm)	Micro 4/3 (17.3 × 13.0 mm)	APS-C (22.3 × 14.9 mm)	APS-C (22.3 × 14.9 mm)	Full-Frame 35 mm (35.8 × 23.9 mm)	Micro 4/3 (17.3 × 13.0 mm)	APS-C (22.3 × 14.9 mm)
Resolution	12 Mp	20.3 Mp	12.3 Mp	24.2	24.3 Mp	80.6 Mp	24.2
Best $\mu\Delta E_{2000}$	8.1	7.7	7.6	7.5	6	5.7	4.7
Best $\mu\Delta E_{1976}$	11.3	15.2	9.7	10.1	13.9	12.8	7.8
Delt.ae Color Encoding Error (ΔE_{2000})	**	**	**	**	**	**	***
FADGI Ed. 2 (Rieger, 2016)	*	**	**	**	**	**	***
FADGI Ed. 3 (Rieger et al., 2023)	–	–	–	–	*	**	**
Metamorfoze (van Dormolen, 2012)	–	–	–	–	–	–	–
Acceptable level for the herbarium digitization (Nieva de la Hidalga et al., 2020)	No	No	No	No	No	Yes after postprocessing	Yes

(Table 1). In general, cameras with macro lenses, usually having smaller aperture and better sharpness, also demonstrated better color accuracy. Interestingly, the recent mirrorless camera Lumix G9 in the testing set (ISO 200, f/5.6, 1/50 s) showed quite a low color accuracy in regular mode, and only after the application of pixel shifting (high-resolution mode) did it appear nearly close to the best results demonstrated by Canon 800D with Tokina Macro 35 mm lens. However, after application of other settings (ISO 200, f/8, 1/15 s, ISO 200, f/5.6, 1/30 s, and ISO 400, f/5.6, 1/60 s) it stable produced images with ΔE_{2000} values 4.6, 4.9, and 5.0, respectively. After the basic postprocessing in the CameraRAW application, it showed even better results with ΔE_{2000} values 4.4, 4.6, and 4.7, respectively. Considering also the higher final resolution of the images (80.6 Mp), Lumix G9 with Olympus 30 mm macro lens seems to be even more perspective photosystem, which will be tested deeply in our further research. At the moment, we can assume that precise choice of the lens and test of different settings in the diapason of ISO 200–400, diaphragm f/4–8, and exposition 1/15–1/60 s is an essential step in setting up the photosystem.

Some authors (e.g., iDigBio. 2014; Harris & Marsico, 2017; Takano et al., 2019) recommend applying ISO 100 and smaller exposition (up to 1/200 s). We found that this highly depends on the illumination, and even ISO 400 results in good-quality images. Similarly, ISO 400 is proposed for digitization purposes by Baratè et al. (2020). As we found, it is better to avoid aperture values higher than f/3.5 as they result in images with somewhat blurred contours of specimens and more vignetting. It is also good to avoid the apertures below f/8 since they often result in arising chromatic aberrations. ISO over 400 should be avoided since it results in losing image details and increased noise.

To stress the requirements of Nieva de la Hidalga et al. (2020), who declared a minimally acceptable level of $\Delta E_{2000} < 5$ for all kinds of image use, including Internet publishing and preservation, we downloaded random images from ten virtual herbaria and compared calculated ΔE_{2000} values with those obtained using LWS's photosystem. The raw obtained data are represented in Appendix A. The basic statistics on obtained data are represented in Table 2, where the herbaria consulted are organized from the lowest to highest demonstrated ΔE_{2000} value. The same statistics have been visualized on the graph (Fig. 1). As we can see, only two herbaria (L and NY) provide images with ΔE_{2000} values lower than 5, hence, meeting the criteria of Nieva de la Hidalga et al. (2020). US, GZU, BM, BR, and P provide only some images having $\Delta E_{2000} < 5$, while other images demonstrate significantly higher ΔE_{2000} values. The remaining herbaria, W, B, PI, and LWS (with minor exceptions), provide images with higher ΔE_{2000} values.

Interestingly, the images from P, PI, W, and B virtual herbaria show the mean ΔE_{2000} value, which is similar or even higher compared to that in the photos obtained by the camera built into the smartphone Samsung Galaxy S10. This does not mean that smartphones can be generally accepted for digitization purposes. It instead points to the progress in the quality of digital cameras, which is also reflected in the stricter requirements of the current FADGI guide (Rieger et al., 2023) compared to its previous edition (Rieger, 2016). However, we suggest that in extreme situations, like in the case of hostilities, smartphones with good-quality cameras can serve as an alternative for the urgent digitization of natural history collections. Such urgent virtual back-upping of the collections could be the only chance to save them. Nevertheless, in such a case, attention should be paid to the quality of illumination that cannot be provided by smartphone LED flash. Hence, external illuminators (at least two oppositely placed household LED lamps with 6500 K) are strictly required.

Hence, if taking into account the complete set of tested images from different virtual herbaria, most of them do not meet the color accuracy criteria set by Nieva de la Hidalga et al. (2020). The digital images of herbarium specimens of any resolution and quality cannot fully substitute the original material for research purposes. They serve rather for preliminary evaluation and validation of the data provided on specimens' labels. Hence, an acceptable ΔE_{2000} value, perhaps, should be extended to

Table 2. Basic statistics on ΔE_{2000} value for images provided by different herbaria and its correspondence to current quality requirements. Bold font indicates the $\Delta E_{2000} < 5$.

Characteristics	L (jpeg)	NY (jpeg)	US (jpeg)	GZU (tiff)	BM (tiff)	BM (jpeg)	BR (jpeg)	LWS (jpeg)	P (jpeg)	PI (tiff)	W (tiff)	B (jpeg)
N	30	30	30	30	30	30	30	30	30	30	30	30
Min	**1.45**	**3.56**	**3.23**	**4.27**	**4.36**	6.10	**2.79**	6.44	**3.98**	5.97	5.35	5.73
Max	**2.75**	5.72	7.04	6.53	7.02	9.78	11.55	9.98	11.96	11.30	16.39	15.62
Mean	**1.94**	**4.62**	5.25	5.31	5.67	8.48	6.86	7.65	8.06	8.55	9.68	10.91
Standard deviation	0.38	0.61	1.09	0.62	0.74	1.23	2.26	0.95	2.55	1.52	3.52	2.53
Median	**1.77**	**4.42**	5.45	5.21	5.73	9.00	7.33	7.43	8.28	8.55	9.02	10.94
Coefficient of variation	19.85	13.26	20.84	11.59	13.05	14.54	33.02	12.39	31.69	17.77	36.35	23.23
Color accuracy levels of images following FADGI Ed. 3 (Rieger et al., 2023)	****, ***	**, *	***, **, *, –	**, *	**, *, –	*, –	***, **, *, –	** (outliers), *, –	**, *, –	*, –	*, –	*, –
Mean color accuracy level of images following FADGI Ed. 3 (Rieger et al., 2023)	****	**	*	*	*	–	–	–	–	–	–	–
Acceptable level for the herbarium digitization (Nieva de la Hidalga et al., 2020)	Yes	Yes	Partly	Partly	Partly	No	Partly	No if outliers excluded	Partly	No	No	No

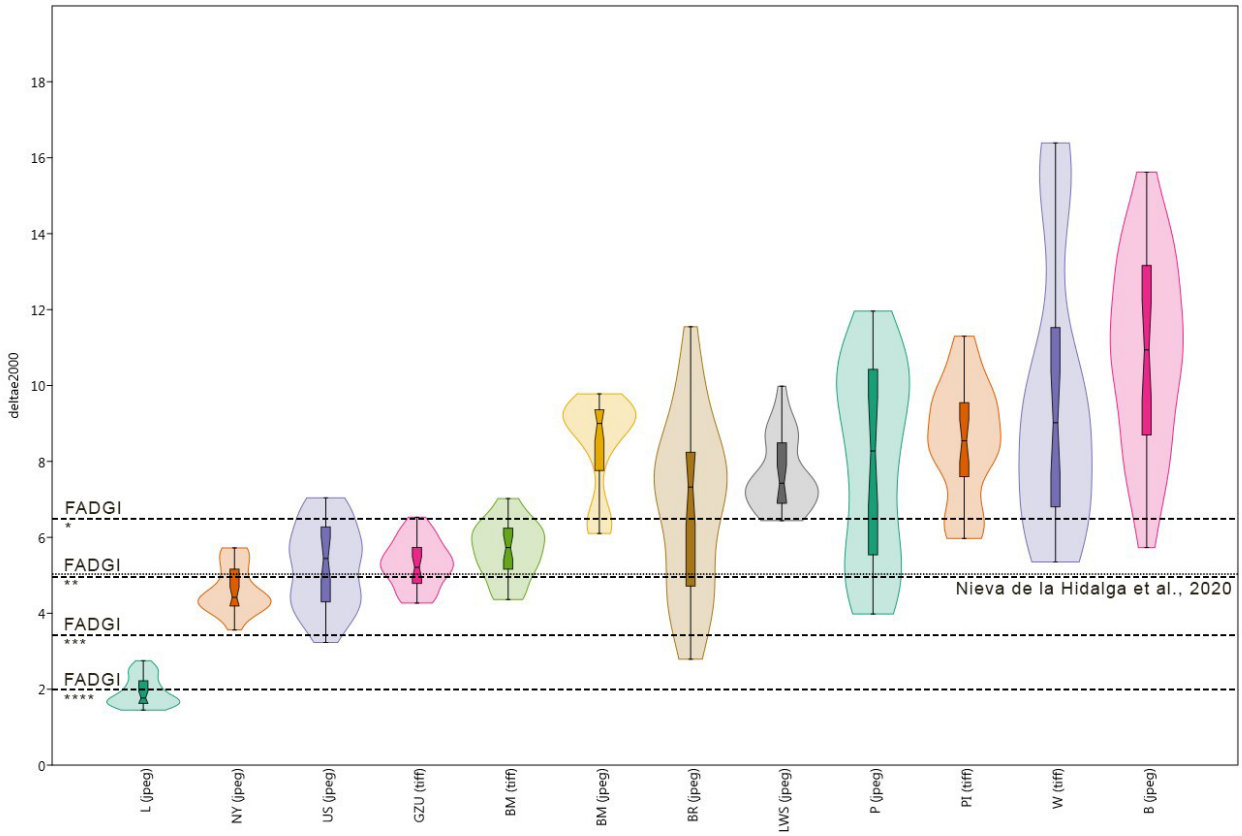

Figure 1. The violin and box plot graph demonstrating the variation of ΔE_{2000} value for images provided by different herbaria. Whiskers represent standard deviations; central lines at notches represent medians.

6.5, which corresponds to the FADGI's one-star quality level (Rieger et al., 2023).

The variation of quality of provided images has been observed in all virtual herbaria consulted but is the highest in W, BR, and P. It is perhaps due to the long period of digitization of their collections and/or application of photosystems of updating quality during this period. It is worth noting that the coefficient of variation of ΔE_{2000} for LWS's images is one of the smallest among tested herbaria, which points to the stable quality of obtained images due to the use of the same protocol and photosystem.

Only L herbarium provides images corresponding to FADGI's four-star and three-star levels (Rieger et al., 2023) with $\Delta E_{2000} < 2$ (Table 2; Fig. 1). US and BR herbaria provide some images of three-star level, but in general have images of one-star level or out of acceptable range (i.e., with $\Delta E_{2000} > 6.5$). Herbarium NY provides most images corresponding to FADGI's two-star level with $\Delta E_{2000} < 5$, and some images of one-star level with $\Delta E_{2000} < 6.5$. Similarly, GZU, BM, and P herbaria provide some images of two-star level, but on average, they have only one-star images or are out of the acceptable range. PI, W, and B herbaria provide some images of one-star level, but generally, their images do not meet FADGI's criteria regarding color accuracy. By analogy, LWS herbarium has only exceptional images of two star-level, while most images meet only one-star level or do not meet FADGI's criteria. In conclusion, the color accuracy of images provided by LWS is similar to those in PI, W, and B herbaria and very close to those in P and BR, but generally requires improvement to meet recent standards.

The color accuracy, along with bit depth, is one of the main criteria Nieva de la Hidalga et al. (2020) ascertained for digitizing herbarium materials. However, it is unclear why much attention is paid to color accuracy reproduction if preserved specimens are already dried and lost their

living natural colors in herbarization and during further preservation. Probably, more attention should be paid to the spatial accuracy of images of the preserved specimens, including herbarium ones. The resolution, sharpness (postprocessing sharpening of master images is restricted by Metamorfoze and FADGI – van Dormolen, 2012; Rieger et al., 2023), geometric distortion, and presence of artifacts are more important criteria for the digitization of preserved specimens, since they can affect the morphological characters important for taxonomic work or identification of digitized specimens. However, the spatial accuracy of obtained images cannot be evaluated using regular color targets (e.g., ColorChecker or Kodak Color Control Patches) commonly applied during digitization. To assess the spatial accuracy of obtained images, advanced targets like Golden Thread Object Level Target (applied at the herbarium L) or Image Engineering Scan Reference Chart TE263 (applied at the herbarium KRAM) are necessary.

Conclusions

The current LWS's photosystem demonstrated the best results regarding color accuracy reproduction compared to other tested photosystems. It was shown that the full-frame camera does not guarantee better color accuracy of obtained images, and the primary attention should be paid to the lens quality instead. Nevertheless, the current LWS's photosystem produces most images with color accuracy that does not meet recent FADGI's (Rieger et al., 2023) minimal requirements ($\Delta E_{2000} < 6.5$) and criteria ascertained by Nieva de la Hidalga et al. (2020) for the herbarium digitization purposes ($\Delta E_{2000} < 5$). It can produce images of better color accuracy ($\Delta E_{2000} = 4.7$), meeting the mentioned criteria, but this requires further optimization and camera adjustment. On the other hand, it produces images of the same or even better quality than those provided by some virtual herbaria (i.e., P, PI, B, and W). Hence, there also arises the question about the acceptable limit of ΔE_{2000}, which probably should be leveled to 6.5 compared to 5 units ascertained by Nieva de la Hidalga et al. (2020).

It was also shown that the Samsung Galaxy S10 smartphone's camera could produce images with the same or even better color accuracy compared to some images from P, PI, W, and B herbaria. Hence, we suggest that in extreme situations, like in the case of hostilities, smartphones with good quality cameras and additional external illumination can serve for urgent digitization of the natural history collections.

Finally, we doubt the application of commonly used color targets for digitizing preserved specimens since the original coloration of such specimens is usually lost. Instead, it would be more useful to apply targets for evaluating the spatial accuracy of obtained images since digital images can incorrectly represent the important morphological characters of preserved specimens.

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Appendix A. Tested ΔE_{2000} values for images provided by different virtual herbaria.

Herbarium acronym	LWS		BR		L		P	
Data source	http://dc.smnh.org/		https://www.botanicalcollections.be		https://bioportal.naturalis.nl/		https://science.mnhn.fr/institution/mnhn/collection/p/list	
Image format	jpeg		jpeg		jpeg		jpeg	
	Specimen's image	ΔE_{2000}	Specimen's image	ΔE_{2000}	Specimen's image	ΔE_{2000}	Specimen's image	ΔE_{2000}
Tested images	LWS114876	7.27	BR0000005610143	4.44	L2706121	1.77	P05606059	7.91
	LWS115814	7.13	BR0000005251551	8.07	L4227700	2.58	P05604378	7.65
	LWS110057	8.98	BR0000005085590	6.56	L1824123	1.65	P05556372	11.94
	LWS108434	7.28	BR0000005268429	9.71	L1824121	1.61	P06616638	10.98
	LWS112356	8.58	BR0000005269457	11.55	L1824100	1.77	P06614510	4.67
	LWS114666	6.83	BR0000005268962	10.05	L1664736	1.5	P06665729	4.76
	LWS064350	7.09	BR0000005599288	6.45	L1664752	1.53	P06664725	3.98
	LWS012269	7.07	BR0000005574506	8.96	L2048207	1.74	P06643009	5.78
	LWS074085	8.79	BR0000005610044	4.61	L1664728	1.68	P06872198	9.49
	LWS097168	7.69	BR0000005610129	4.4	L1664518	1.63	P06898681	10.03
	LWS093189	9.98	BR0000005612376	3.99	L4201532	2.75	P05572674	4.16
	LWS104671	7.54	BR0000005610310	4.75	L4206155	2.52	P06169913	10.41
	LWS082301	6.46	BR0000005647286	5.38	L3912403	2.06	P05348062	4.85
	LWS090820	7.34	BR0000005692408	2.93	L3880536	2.11	P05349490	9.55
	LWS090821	8.92	BR0000005693276	3.84	L3798683	2.48	P05349809	8.89
	LWS092529	8.41	BR0000005756421	8.18	L3421811	2.43	P05352452	11.96
	LWS095436	6.52	BR0000005749218	8.94	L3422024	2.57	P05413635	9.93
	LWS117591	6.69	BR0000005751273	8.42	L3798348	2.35	P05401397	10.61
	LWS041914	8.46	BR0000006010706	7.54	L1826712	1.66	P00114597	5.73
	LWS041798	6.62	BR0000006014834	7.56	L1826706	1.61	P05325382	10.48
	LWS104998	8.71	BR0000006397081	7.75	L1729042	1.55	P05330196	10.47
	LWS045196	7.62	BR0000006386917	6.7	L1726296	1.59	P05377102	8.15
	LWS081841	7.53	BR0000006445683	7.64	L1712761	1.67	P05345786	10.06
	LWS111288	9.42	BR0000006468316	6.42	L1714522	1.87	P05356212	10.97
	LWS117303	6.92	BR0000006651022	7.7	L1229311	1.45	P05338196	6.28
	LWS007193	6.78	BR0000009737181	7.16	L3017598	1.86	P05338210	7.54
	LWS007104	7.4	BR0000011661016	5.15	L3012534	2.18	P00102771	8.4
	LWS116675	6.44	BR0000008547156	10.62	L4172147	2.1	P00102794	4.87
	LWS059278	7.45	BR0000019150062	2.79	L2048207	1.74	P00095479	6.28
	LWS059277	7.48	BR0000028193302	7.49	L1723201	2.05	P00455987	4.97
Excluded outliers	LWS118511	4.71			L4307171	10.22	P05094218	14.98
	LWS117185	4.9			L2070825	8.57		
					L1664519	3.9		
					L3299057	3.55		

Appendix A. Continued.

Herbarium acronym	B		US		NY		W	
Data source	https://herbarium.gbif.de/		https://collections.nmnh.si.edu/search/botany/		https://sweetgum.nybg.org/science/vh/		https://www.jacq.org/	
Image format	jpeg		jpeg		jpeg		tiff	
	Specimen's image	ΔE_{2000}	Specimen's image	ΔE_{2000}	Specimen's image	ΔE_{2000}	Specimen's image	ΔE_{2000}
Tested images	B10 0612505	11.64	US02657192	5.71	NY01154240	5.13	W0022412	9.08
	B10 0762104	13.29	US02036841	5.7	NY00659014	4.06	W20180011081	9.5
	B10 0463047	10.95	US01638693	6.72	NY00278673	4.47	W19260002399	6.95
	B10 0720818	12.7	US02295206	5.72	NY01111411	3.62	W0198224	5.87
	B10 0295345	8.83	US02295544	5.81	NY01207928	3.56	W20150015230	9.53
	B10 0062990	13.67	US02295466	5.55	NY00380615	4.16	W20040015205	7.93
	B10 0498955	10.66	US02299047	6.32	NY01041711	4.4	W19940007184	10.12
	B10 0194679	11.76	US01236911	3.23	NY01240070	4.91	W19940005381	9.43
	B10 0501215	11.45	US02910399	6.48	NY01240069	4.6	W19750014148	8.2
	B10 0401925	12.48	US03315596	6.41	NY00429915	5.71	W19710021586	8.59
	BW15774010	6.59	US03558373	5.22	NY00579492	4.2	W19730010518	10.22
	B10 0580201	14.33	US03648212	3.91	NY00429301	4.17	W18890358074	7.93
	BW09847010	10.93	US03655213	4.27	NY00415855	4.41	W19160040971	7.06
	BW09840030	9.75	US03708428	4.3	NY00429300	4.14	W19110006601	16.39
	BW09846020	10.39	US03708743	3.84	NY00415847	4.42	W18890344142	6.36
	B100356299	5.73	US03965306	3.66	NY00415854	4.23	W18890343339	6.07
	B100628095	11.66	US00498975	5.55	NY00381397	4.96	W18890176850	7.19
	BW00879010	8.09	US01341530	4.56	NY00353423	5.55	W18890169647	15.49
	BW00882010	8.3	US01351765	5.63	NY00353390	5.64	W18890116066	11.12
	B100626453	15.62	US01418103	7.03	NY00353343	5.26	W18890167221	10.33
	B100463256	14.59	US01418118	6.84	NY00353304	5.59	W18890103497	16.35
	BW17516010	8.13	US01638679	7.04	NY00353320	5.72	W18890105101	14.94
	BW18366010	7.3	US03034171	4.66	NY00335712	4.25	W18890078203	14.94
	BW18366040	7.95	US01562628	6.26	NY00250998	4.54	W0074239	12.74
	B100279026	9.41	US00371149	5.34	NY00232257	4.42	W0209299	6.14
	B100277369	10.6	US00315479	3.81	NY00180101	4.25	W0205862	5.35
	B100576703	13.12	US03910541	4.58	NY00074332	4.49	W0031990	6.09
	B100629675	13.3	US03910533	4.3	NY00162932	4.08	W0064125	8.96
	B101041345	13.85	US03825241	4.6	NY00025829	4.28	W0017426	15.84
	BW06535010	10.23	US03825258	4.56	NY00004050	5.29	W0022052	5.64
Excluded outliers			US03018521	18.7	NY00709539	7.39		
					NY01081819	9.96		
					NY01082967	8.71		

Appendix A. Continued.

Herbarium acronym	BM		BM		GZU		PI	
Data source	https://data.nhm.ac.uk/		https://data.nhm.ac.uk/		https://www.jacq.org/		https://www.jacq.org/	
Image format	tiff		jpeg		tiff		tiff	
	Specimen's image	ΔE_{2000}	Specimen's image	ΔE_{2000}	Specimen's image	ΔE_{2000}	Specimen's image	ΔE_{2000}
Tested images	BM001046253	5.87	BM000521903	6.55	GZU000312195	5.46	PI018084	6.46
	BM001134949	6.95	BM000051636	6.41	GZU000330246	5.72	PI023399	10.08
	BM001125317	5.91	BM000051651	7.04	GZU000302173	6.03	PI016605	6.69
	BM001043579	4.58	BM000522332	6.5	GZU000302171	5.64	PI010679	5.97
	BM001042230	6.19	BM001024837	6.14	GZU000302165	5.59	PI015062	6.09
	BM001009514	5.79	BM001024838	6.14	GZU000302164	6.05	PI015053	5.97
	BM000646123	5.89	BM000946954	9.6	GZU000302124	6.03	PI010503	6.37
	BM001008620	6.38	BM000946956	9.08	GZU000302114	4.35	PI060322	7.82
	BM000885992	5.61	BM000946961	9.78	GZU000302105	6.53	PI062216	8.02
	BM000646237	6.03	BM000936510	8.3	GZU000302045	4.71	PI058931	10.02
	BM000040272	4.48	BM000936516	8.44	GZU000299033	5.15	PI058227	8.32
	BM000557808	5.11	BM000829164	8.83	GZU000302036	4.8	PI054634	9
	BM000646120	5.57	BM000939392	9.36	GZU000299772	5.78	PI055889	9.47
	BM000557807	5.18	BM000936518	8	GZU000294923	6.24	PI054590	8.23
	BM000557806	5.47	BM001042975	8.89	GZU000277836	4.37	PI051599	8.57
	BM000557803	5.03	BM001072227	9.42	GZU000294921	6.26	PI052647	6.94
	BM000557664	5.2	BM001072361	9.31	GZU000273692	5.19	PI051525	8.27
	BM000051695	6.38	BM001024842	6.1	GZU000277834	4.4	PI051558	8.53
	BM000051628	5.29	BM000062783	9.37	GZU000273469	5.17	PI051418	7.93
	BM000042611	6.25	BM000939063	8.95	GZU000260591	5.08	PI047655	9.52
	BM000051154	5.67	BM000953182	8.75	GZU000259529	5.51	PI047640	10.17
	BM000051570	6.7	BM000997729	9.33	GZU000259696	4.27	PI043447	11.3
	BM001057204	7.02	BM000997734	9.26	GZU000250661	5.05	PI043446	10.78
	BM001067297	6.39	BM000041699	9.38	GZU000279097	5.17	PI043154	9.45
	BM000954795	4.72	BM000042712	9.4	GZU000277963	5.16	PI035023	9.57
	BM001042138	4.41	BM000939451	8.81	GZU000250527	5.47	PI033791	8.51
	BM000938607	5.28	BM000939449	9.71	GZU000120870	4.56	PI040569	9.26
	BM000646067	6.2	BM000946986	9.17	GZU000249376	4.75	PI021697	10.98
	BM000042227	4.36	BM001024149	9.05	GZU000093404	5.23	PI030571	9.54
	BM000609397	6.24	BM001024147	9.36	GZU000249715	5.5	PI030557	8.56
Excluded outliers	BM001134966	10.83	BM000895849	12.85	GZU000251150	10.03		
	BM000589029	11.89	BM000895855	13.38	GZU000251754	10.74		
	BM000621852	9.42	BM000895858	11.62	GZU000250659	9.35		
	BM001008628	3.76	BM000895860	12.66	GZU000249458	8.46		
			BM000042612	11.64				
			BM000946985	10.41				

Тестування бюджетних фотосистем з метою досягнення оптимального результату для цілей оцифрування гербарію

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Ця робота стосується питання застосування різних бюджетних фотосистем для оцифрування гербарних зразків. Було випробувано дванадцять фотосистем щодо точності кольоропередачі зображень, які вони продукують. Встановлено, що фотосистема, побудована на базі фотоапарата Canon EOS 800D та фіксованого об'єктива Tokina AT-X M35 PRO DX AF 35 mm f/2.8 Macro, яка зараз використовується для оцифрування гербарної колекції LWS, показала найкращі результати серед інших протестованих фотосистеми. Ця фотосистема також продукувала зображення з такою ж або навіть кращою точністю кольоропередачі, як і зображення, завантажені з віртуальних гербаріїв P, PI, B і W. Тим не менш, точність кольоропередачі, виміряна як ΔE_{2000}, загалом не відповідає останнім критеріям, встановленим для цілей оцифрування гербарію та новим вимогам FADGI. Було виявлено, що ця фотосистема має потенціал для вдосконалення, а отже, її слід оптимізувати. З іншого боку, також було показано, що смартфон Samsung Galaxy S10 може створювати зображення з такою ж або навіть кращою точністю кольоропередачі порівняно з деякими зображеннями, збереженими у віртуальних гербаріях P, PI, W і B. Тому, в умовах екстремальних ситуацій та бойових дій такі смартфони з додатковим зовнішнім освітленням можуть слугувати для екстренного оцифрування природничих колекцій. Поза тим, ми сумніваємося у необхідності застосування загальновживаних кольорових мішеней для оцифрування гербарних зразків, оскільки оригінальний колір таких зразків зазвичай втрачається під час гербаризації та збереження. Замість цього було б більш доцільно застосовувати розширені мішені для оцінки просторової точності зображень, оскільки зображення можуть спотворено відображати важливі морфологічні характеристики таких зразків.

Ключові слова: оцифрування гербарію, оцінка якості зображень, фотосистеми, дельта Е, точність кольоропередачі