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ARTICLES

Genetically Modifying Livestock for Improved Welfare: A Path Forward

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Abstract In recent years, humans' ability to selectively modify genes has increased dramatically as a result of the development of new, more efficient, and easier genetic modification technology. In this paper, we argue in favor of using this technology to improve the welfare of agricultural animals. We first argue that using animals genetically modified for improved welfare is preferable to the current status quo. Nevertheless, the strongest argument against pursuing gene editing for welfare is that there are alternative approaches to addressing some of the challenges of modern agriculture that may offer ethical advantages over genetic modification; namely, a dramatic shift towards plant-based diets or the development of in vitro meat. Nevertheless, we provide reasons for thinking that despite these possible comparative disadvantages there are important reasons for continuing the pursuit of welfare improvements via genetic modification.

Keywords Animal welfare · Genetic engineering · Gene editing · CRISPR · Biotechnology · Genetic modification

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Introduction

The proposal to genetically modify animals with an aim of improving animal welfare has been debated in the bioethics literature for roughly the past three decades. Since the earliest writings, however, humans' ability to selectively modify genes has improved dramatically, particularly as a result of the development of new technologies that allow for increased precision and efficiency. The development of gene-editing technology has sparked a range of novel ideas about how to address challenges associated with modern agriculture, including negative impacts on human health, the environment, and animal welfare.

In what follows, we argue that societies currently relying extensively on intensive confinement of animals for food production ought to pursue research investigating the potential of gene-editing technology to improve farm animal welfare. To support this conclusion, we first present consequentialist and deontological reasons for believing that gene-editing technology can result in welfare improvements in livestock that are ethically preferable to the current status quo. We then consider arguments that the current status quo is preferable to a future utilizing gene editing for welfare improvements, and argue that these arguments fail. Finally, we compare gene editing for welfare to other alternatives to the status quo and suggest that while some of these alternatives are indeed ethically preferable, there nevertheless are good reasons for pursuing research into opportunities for improving farm animal welfare via gene editing.

The Ethical Case for Gene Editing as Preferable to the Status Quo

In order to assess the ethical implications of the extensive use of gene editing with an aim of improving welfare, we need to consider what alternatives exist to this proposal. In this section, we will compare gene editing to the current status quo in modern agriculture. We examine other alternative approaches later in the paper.

There are numerous welfare problems associated with current practices in animal agriculture. For the sake of argument, we will restrict our arguments to intensive confinement, which we define as housing conditions where farm animals' natural behaviors are severely restricted by limited space and/or high stocking densities for an extended period of time. In modern agriculture, many animals are confined in cramped, artificial environments that prevent them from engaging in natural behaviors, resulting in the frustration of innate desires. The frustration of desires is itself problematic from a welfare perspective, and the artificial conditions can also exacerbate other potential welfare problems, such as aggression between animals and susceptibility to disease (Fraser et al. 2000). Many routine agricultural procedures used to mitigate some of the consequences of intensive confinement, such as dehorning (Faulkner and Weary 2000) and tail-docking of cattle (Fulwider et al. 2008), castration of pigs (Puppe et al. 2005; Taylor et al. 2001), and beak trimming of poultry (van Liere 1995; AVMA 2010), are often performed without the use of painkillers, resulting in both immediate and often chronic pains.

Even considering only this limited sampling of welfare problems, it is clear that if animals are capable of suffering from negative emotional states, then modern animal agriculture is responsible for significant suffering. Due to space constraints, our arguments will begin from an assumption that mammals and birds are capable of suffering, which we take to reflect the beliefs of a majority of the public as well as the conclusion of prominent scientific panels tasked with investigating the issue (see Varner 2012, Chapter 5 for a comprehensive discussion of the evidence). Since tens of billions of birds and mammals are kept in intensive confinement during some part of their life, even a relatively small amount of "per animal" suffering would mean that modern agriculture is responsible for an exceptionally large amount of suffering.

According to consequentialist ethical theories, the rightness of actions or practices is wholly determined by the consequences that result from them. On such views, ethical choices are those that maximize good consequences and minimize bad consequences. According to almost all plausible contemporary consequentialist accounts, states of suffering count as instances of bad consequences. As such, actions or practices that result in less suffering will be, all other things being equal, preferable to actions or practices that result in more suffering. Starting from a consequentialist perspective, gene editing farm animals would then be preferable to the status quo if it (A) results in less suffering among farm animals than the status quo and (B) does not result in a loss of good consequences and a gain of bad consequences that together outweigh the disvalue of the suffering.

Can gene editing facilitate the reduction of suffering among farm animals? We suggest that recent breakthroughs in gene-editing technology have dramatically increased the likelihood that it can. New gene-editing technologies utilize designer nucleases (which can be thought of as "molecular scissors") to make precise breaks at target sequences of DNA. Zinc finger nucleases (ZFNs), transcription activator-like effector nucleases (TALENs), and clustered regularly interspaced short palindromic repeats-CRISPR associated proteins (CRISPR-Cas) systems are commonly used technologies in gene editing today. In contrast to previous technologies, these gene-targeting systems appear to be universally applicable, with no limits on which species they can be used to modify. In virtue of their precision, ease of use, and universality, these tools are more powerful than their predecessors and have revolutionized possible applications of genetic engineering.

Though no animals genetically engineered for improved welfare are currently used in commercial agriculture, there have been several recent studies suggestive of ways in which genetic modification could improve farm animal welfare and reduce suffering. Thus far, farm animals have been genetically modified for increased resistance to or reduced transmissibility of diseases including mastitis (Wall et al. 2005; Liu et al. 2014), tuberculosis (Wu et al. 2015; Gao et al. 2017), porcine reproductive and respiratory syndrome (Burkard et al. 2017), and avian influenza virus (Lyall et al. 2011). Cows have also been genetically modified to be hornless (Carlson et al. 2016), which could eliminate the practice of dehorning, an invasive and painful procedure used by the dairy industry. Relatedly there are also opportunities under investigation to reduce the need for piglet castration (Tan et al. 2013; Carlson et al. 2014). And genetic engineering has been used to induce the

growth of blunt, short beaks in chicken embryos (Bhullar et al. 2015). This novel beak shape appears similar to the shape that is obtained when chickens have their beaks trimmed, so there is potential for this sort of genetic modification to provide an alternative to beak trimming.

In addition to the above research which has been conducted directly on farm animals, there have also been more speculative proposals about how gene-editing technology could eliminate suffering, including proposals to eliminate farm animals' capacity to experience pain. One frequently cited problem with this idea, however, is that pain plays a protective role for animals and as such is essential for growth and survival. Various proposals have been put forward to address this concern. Based on promising knock-out research on mice, Shriver (2009) proposed using gene editing to create livestock who have some preserved protective behavior but lack the affective dimension associated with the unpleasantness of pain. John Wood and colleagues have shown that congenital insensitivity to pain, a condition where one lacks any ability to feel pain, can be reversed in humans and mice with chemical compounds that block the effects of endogenous opioids (Minett et al. 2015), leading to an innovative proposal to create genetically modified animals where the capacity to feel pain can be present when needed but otherwise completely "switched off" (Esvelt 2016). And Gary Comstock (1992) discussed, as a thought experiment, genetically modified "chickens" who lacked eyes, ears, nerve-endings and any awareness whatsoever. These chickens would presumably not be at risk for injury since they wouldn't engage in any behaviors at all.

Using gene-editing technology to reduce disease, eliminate painful procedures, and eliminate the capacity for pain altogether would, all things being equal, decrease suffering and hence create a better state of affairs according to consequentialist reasoning. The question, of course, is could all other things truly be equal if these changes were made? Assuming that the changes themselves directly reduced some suffering, would the diminishment of suffering be offset by losses in positive consequences or the creation of other negative consequences?

Regarding the former suggestion, many people seem to believe that if you lose the capacity to feel pain you would also lose the ability to experience positive feelings, and so one might worry that the elimination of pain would be depriving the animals of important positive experiences. This might be true in the sense that we can better appreciate some positive experiences when we know what it's like to live without them, but it is a mistake to apply it to the capacity for positive experience more generally, and people with congenital insensitivity to pain have no difficulty experiencing pleasure. Those with anhedonia (the inability to feel pleasure) are certainly capable of suffering. Thus there is no essential biological connection between pleasure and pain such that one can't exist without the other. As such, aside from Comstock's example of the completely insentient chicken, there is no particular reason to suspect that the proposed modifications would result in a loss of any capacity for positive experiences.

It also is worth noting that, in contrast to the suggestion that people switch to a plant-based diet, a full scale switch to agricultural systems using animals with enhanced welfare would not entail any large-scale changes in the food system. From the perspective of the individual animal product consumer, things presumably

wouldn't change much at all, as there doesn't seem to be any particular reason to think that the proposed changes would make animal products more expensive or harder to access. Of course, if consumers did strongly reject genetically modified animals, that would be important to take into account on a consequentialist perspective, so this possibility will be considered more below. But with that promissory note put aside for the time being, we suggest that gene editing for improved welfare is likely to have minimal disruptive effects on most people's experiences and that there is no reason to believe it would result in the diminishment of the animals' capacity for pleasure, so it is unlikely that diminishment of suffering would be outweighed by a significant loss of positive consequences.[1]

We also need to consider whether these changes could in fact result in an increase in negative consequences.[2] One possibility is that the changes would, in the context of the overall system, result in downstream effects that would, in turn, result in decreased welfare for animals. For example, the copious use of antibiotics in modern agriculture reduced the likelihood of some diseases, but also presumably enabled more intensive confinement conditions.[3] One could imagine genetic disease resistance similarly leading some producers to decide to keep animals in even more cramped conditions. This possibility certainly needs to be taken into account, but in general there has been a striking trend over the past several years of companies committing to policies moving away from the worst excesses of intensive confinement, focused on concerns such as the housing conditions of pigs, egg-laying hens, and broiler chickens (discussed more below). It seems unlikely that a public that has been presented with these welfare improvement commitments by these companies would be easily persuaded to ignore those concerns going forward.

In short, on consequentialist reasoning, the likelihood of a significant reduction in suffering, particularly given the scale of current animal agriculture, would dramatically outweigh the chances of losses of positive consequences or increases in negative consequences. As such, there would be strong consequentialist reasons for preferring a system that used animals genetically modified for improved welfare ("welfare-enhanced animals") to the current system.

The arguments are not quite as straightforward for deontological ethical theories, which hold that the rightness of actions is not wholly dependent upon consequences. Nevertheless, we think for a great many deontological accounts that take animals' interests into consideration, there are reasons for preferring the use of welfare-enhanced animals to the status quo.

Consider one of the most influential deontological accounts of animal ethics: Tom Regan's theory of animal rights (Regan 1983). Regan argued that all experiencing subjects of a life, which he took to include at least all adult mammals and birds, possess interests that need to be taken into account in moral reasoning. He believed that properly respecting these interests involves recognizing their inherent value, and suggested that respecting the unique inherent value of each individual is

[1] There are, however, some interesting questions that could arise in relation to companies patenting gene edits and how this would affect consumers and farmers. For more on this, see Gifford (2010).

[2] Thanks to two reviewers for this point.

[3] We thank Dan Weary for this example.

in conflict with utilitarian (and, generally, consequentialist) approaches that treated individuals as mere "receptacles of utility." As such, Regan suggested that proper respect for each experiencing subject of a life led to the conclusion that these individuals possess a right not to be harmed for the benefit of others.

On such an account, it is clear that raising animals for human consumption is morally impermissible, even if those animals have improved welfare. So it would be quite a stretch to ever claim that a Regan-style theory of rights would "endorse" the use of gene editing to improve the welfare of animals used for food production. Nevertheless, his theory does leave room for supporting the claim that the use of animals modified for improved welfare is *preferable* to the status quo. In order to resolve situations where moral duties conflict with one another, Regan introduced additional principles that he believed followed from a basic respect for each individuals' interest. One of these principles was the Worse-Off Principle, which can be stated as follows:

> When we must decide to override the rights of either Group A or Group B, and when the harm faced by Group A would make some of them worse off than any of Group B would be if any other option were chosen, then we ought to override the rights of Group B. (Adapted from Regan 1983, p. 308)

Given that a rights-based view would hold that both groups' rights are violated, the Worse-Off Principle is applicable to an imagined forced choice between the current status quo and a future with welfare-enhanced animals raised for consumption. For Regan, death is the ultimate harm, and in both cases the groups would be killed for human consumption. However, if the genetic modifications resulted in genuine welfare improvements, it follows that non-modified animals would be worse off in virtue of experiencing additional suffering, and as such we would have a duty to avoid violating their rights if faced with a choice between that situation and one that violated the rights of welfare-enhanced animals.

We suggest, then, that many deontological accounts that recognize moral duties to animals would support the claim that welfare-enhanced animals are preferable to the status quo. Though on many of these accounts we would still be violating the rights of animals by raising them for human consumption, we can nevertheless avoid the additional violation of causing animals additional harms. Thus, welfare enhancement is preferable to the status quo, though of course a deontologist who cares about animal rights would never be satisfied with merely moving towards a system that relied on welfare-enhanced animals as a stopping point for change (and see note 9 below regarding the suggestion that these changes would actually impede the types of changes required to satisfy a deontologist).

There is an important caveat here, however. If research on animals is required in order to produce animals that are welfare-enhanced, this could be regarded as using individual animals as a means to an end, and hence in violation of Regan's view. But this could, in theory, be prevented if the research largely avoided the deliberate infliction of harm on animals. Since the genetic modification itself generally occurs in embryos, at a stage of development clearly prior to any possible sentience, one might suggest that a prohibition on using animals as a means to an end would be *neutral* on the modification itself. It is other aspects of the animals' lives, such as

their confinement, subjection to invasive procedures, and eventual killing, that cause harm.

We suggest, then, that there are good prima facie reasons to believe that using welfare-enhanced animals in agriculture is ethically preferable to current practices. Before discussing other alternatives to both approaches, we first turn to potential arguments that could be used to suggest that the status quo is actually better than a welfare enhanced future.

Ethical Arguments that Favor the Status Quo Over Welfare Enhancement

Among the public, one of the most common objections against the use of gene editing is that doing so is wrong because it is "unnatural" (Macnaghten 2004). On such a view, the unnaturalness of using gene editing to modify animals might provide reasons for preferring the status quo. However, as has been extensively discussed in the bioethics literature, it is notoriously difficult to come up with an adequate definition of "natural" that both captures the folk conception of the term and provides clear moral guidance. The common conception of "natural" seems to resemble something like "free from human interference," but a definition along these lines would suggest that airplanes, antibiotics, and most aspects of modern life are unnatural. Most importantly for our purposes, selective breeding techniques currently employed in animal agriculture that attempt to control which genes are selected for and often rely on artificial insemination would not count as natural on such a definition. So the notion of "naturalness," in the absence of further elaboration, does not appear to provide much reason for preferring the status quo.

Similar points can be raised against the religious objection that genetic modification is "playing God." Given that selective breeding allows humans to control (albeit imperfectly) the traits of future generations of livestock and has resulted in dramatic changes in agricultural and companion animals over the last several thousands of years, it is difficult to see why a hard line should be drawn between selective breeding practices and the use of gene-editing technologies. There are more specific ways of formulating the naturalness and "playing God" objections that attempt to differentiate agricultural biotechnology from "traditional" farming practices, but Comstock (2000) has chronicled many iterations of these claims and explained why they fail to show that there is something intrinsically wrong with genetic modification.

Aside from these concerns, one consideration related to public conceptions of naturalness is the idea that genetic modification might lead to unpredictable long-term consequences that have serious negative effects. Indeed, humans have a long track record of failing to anticipate the consequences of our technological developments. But note that this concern is relevant to almost all new technological developments, so for it to count as a particularly strong argument against welfare enhancement we should have some reasons for thinking that this development might be particularly prone to risk. Of course food products from genetically modified sources should be subject to rigorous safety testing, but thus far we do not see any

evidence to suggest that genetically modified foods are likely to carry special health risks compared to other new chemical compounds introduced into the market. And unlike in the case of pollinating crops, genetically modified livestock do not carry risks of transferring genes to the surrounding environment.

Moving toward objections more rooted in contemporary philosophical ethics, in a recent article, Paul Thompson (2008) usefully sorted critics of the use of genetic manipulation to improve animal welfare into three categories: those who think that a common "yuck factor" response to genetic engineering should carry moral weight, those who argue that genetic engineering harms animals in ways that were not previously taken into account, and those who think that changing animals does not necessarily harm the animals themselves but violates species integrity. We follow Thompson in concluding that each of these objections is flawed, though we will add our own thoughts as to why the objections fail.

As is frequently cited by ethicists writing on the topic, many people react negatively to the idea of genetically engineering food animals when it is first proposed to them. This is backed up, indirectly, by public polling, which has consistently shown that a large portion of the population is opposed to the idea of eating cloned or genetically engineered animals and specifically indicate more concern about the genetic modification of animals than of plants (Hallman et al. 2004; Hossain and Onyango 2004). The frequent emphasis on the negative reaction in the bioethics literature is also, no doubt, influenced by many of the authors' personal experiences with student and public reactions to various philosophical thought experiments about genetic engineering.

Thompson, citing Rollin, describes this reaction as an "aesthetic response" that "has no moral force" and "is morally unjustified in the face of practical opportunities to alleviate the distress of farm animals" (2008, p. 312). We agree; morally-charged emotional reactions to new proposals may be indicative of serious underlying moral concerns but should not themselves be taken to have any moral force apart from whatever reasons can be put forward. In addition to this fairly straightforward point about the methodology of ethical discourse, we also suggest that there's good reason to believe that ethicists' emphasis on the public's moral revulsion towards genetically engineering food animals may exaggerate the true shape and scope of opposition.

Though there has been substantial investigation of public attitudes towards genetic modification more generally, there has, to our knowledge, not been systematic investigation of public attitudes towards the specific idea of making welfare improvements via gene editing. But, one might object, if the public is opposed to gene editing animals more generally, then it surely is also opposed to gene editing for the sake of welfare, especially considering how little most people tend to prioritize animal welfare in their everyday life. We offer two reasons for questioning this assumption.

First, there is a substantial body of evidence from the social psychology literature showing that disgust reactions are strongly linked to negative moral judgments. Disgust acts as a moral emotion related to food and sexual taboos in many cultures (Rozin 1990). In one study, Haidt et al. (1993) found that feelings of disgust often predicted strongly negative moral evaluations of acts like eating a dead family pet, a

brother and a sister kissing one another, and sexual intercourse with a dead chicken far better than did beliefs that the actions would cause harm. Building off of these findings, researchers hypnotized subjects and trained them to associate particular words with the feeling of disgust (Wheatley and Haidt 2005). Following this, the previously hypnotized subjects and a control group both read two identical sets of passages describing an action, one of which contained some of the words that the subjects had been taught to associate with disgust while under hypnosis. The previously hypnotized subjects judged the actions as more wrong than the control group in the cases that used these words, but not in the other cases, indicating that the feeling of disgust was influencing their moral judgments. In a related study, two groups of people watched videos prior to reading a description of an event (Schnall et al. 2008). One group watched a video of a scene from the movie *Trainspotting* that involved feces and vomiting while the other group watched a benign movie scene. The group that watched the disgusting scene judged the action much more harshly in moral terms.

The literature has established that disgust reactions can predict certain moral evaluations, particularly those related to sex and food, and that manipulating disgust reactions can induce stronger negative moral evaluations of actions that are thought to be harmless. Moreover, research by Clifford and Wendell (2016) found that people with greater sensitivity to disgust were more likely to support mandatory labeling of genetically modified organisms as well as outright bans on genetically modified organisms, so there's evidence that some opposition to genetic modification is related to initial disgust reactions.

Why is this relevant to an evaluation of public attitudes towards genetic engineering? We hypothesize that there is likely a large gulf between people's disgust reactions to more extreme-sounding versions of genetic engineering, such as headless chickens, painless animals, and chimeras, compared to more subtle changes such as hornless cows, pigs with more environmentally efficient digestion, or disease-resistant chickens. When survey respondents are asked about genetic engineering (or modification) and animals more generally, it is unclear what conception of genetically modified animals participants are using to answer the question, and so it would be a mistake to make strong inferences about the more subtle changes based on general questions that could evoke thoughts of the more dramatic proposals.

Moreover, though it certainly can be tempting to be cynical about the idea that the public cares much about animal welfare, concern for welfare could be influencing responses to questions. Questions thus far about genetically modifying animals have not focused on welfare-enhancement. A general question such as "How do you feel about the use of GM to create animal-based food products?" (Hallman et al. 2004) might suggest to participants that the animals are being harmed for the sake of human benefits. So a question that asked about using GM to create hornless cows, in order to eliminate painful dehorning surgeries, could elicit different reactions.

We think the above reasons are sufficient to undermine the assumption that the public will strongly resist the use of gene editing to improve welfare.[4] At the very least, far more data, and data more directly relevant to our proposals, needs to be produced. And there remains a further question about how views will shift over time; even if the public is currently opposed to more extreme thought experiments related to gene editing, we know very little about how these views would shift over time after more gradual changes occurred.

Next, consider claims that genetically "diminishing" animals to be lacking some capacity is thereby causing the animals harm. We will consider two versions of this argument. The first version holds that by genetically modifying an animal we are in fact diminishing the overall welfare of that animal (despite some welfare improvements produced by the changes). The second version acknowledges that the welfare of the animals has improved, but argues that considerations that go "beyond welfare" (Ortiz 2004) imply that animals are nevertheless "worse off" as a result of the changes.[5] These two types of arguments appear to underlie the terminology that suggests that various welfare improvements for animals are "diminishments" or "disenhancements" of the animals.

Regarding the argument that genetic modifications are bad for the animals' overall welfare, the creation of a line of blind chickens to reduce cannibalism (Ali and Cheng 1985) was a major touchstone for discussion and ethical debate (Sandøe et al. 1999) about the welfare implications of species modification, though this experiment involved selective breeding rather than genetic engineering. Later research suggested that the chickens exhibited strange behaviors (air pecking, circle walking) possibly indicative of diminished welfare (Collins et al. 2011), but even if the behavioral changes observed were minimal aside from a drop in aggression between chickens, various authors argued that the modification would be depriving the chickens of the positive experiences of sight and thereby diminishing their well-being. One might similarly argue that the loss of horns of cattle is depriving them of some positive welfare states associated with their horns and the loss of a sharp beak is depriving chickens of some other welfare benefits (though of course most cattle lose their horns and most chickens their beaks in modern agriculture regardless, so this wouldn't be a strong argument on behalf of the current system).

Recent philosophical arguments examining the relationship between disabilities and well-being are relevant here (Barnes 2016). Many disability advocates have been critical of philosophers' willingness to rely on their own intuitions in assuming that various disabilities result in "lives that are not worth living." As has been well-established, the empirical evidence shows that most people's intuitions about how various conditions will impact human well-being are frequently off-the-mark.

[4] In fact, we have preliminary data that bolsters our case. In a survey using Amazon's Mechanical Turk, we found that a majority of participants accepted the use of genetic modification to create hornless cows. In another set of questions, we found that describing *modifications as being done for the purpose of improving welfare* appeared to influence participants' responses towards being more favorable.

[5] We are classifying Ortiz's argument in a manner that is different than Thompson's original article. Thompson situated his argument in the first category, but we include it here because Ortiz repeatedly references the idea that the changes will interfere with what is for an animal's "own good" (2004, p. 115) even if they do not diminish welfare.

Diener and Diener (1996), in an article titled "Most People Are Happy," reviewed the literature and found that the blind, people with severe spinal injuries, and those with quadriplegia all reported significant levels of happiness. The phenomenon is so ubiquitous that the expression "the disability paradox" is now used as shorthand to refer to the many instances where disabled individuals report a much higher quality of life than what is predicted by external observers (Albrecht and Devlieger 1999). The point, of course, is not that it is impossible to assess the well-being of people under different conditions, but rather that our initial intuitions about what it is like to be in conditions that are dramatically different from our own are likely to be mistaken.

Not all of the disabilities literature related to human well-being is relevant for thinking about the welfare of genetically modified animals who lack certain capacities. Many of the reasons why it is difficult to be disabled in contemporary, ablest society (e.g. social stigma) as well as many of the reasons disabilities activists cite for valuing their disabilities (e.g. liberating oneself from societal conceptions of normalcy) seem too cognitively complex to apply to agricultural animals. Nevertheless, there are some important lessons that can be applied. First, the general tendency seems to be that we are very poor at predicting well-being in conditions radically different from our own. When we try to imagine what it is like to be in a condition where some capacity we possess is absent, we tend to over-exaggerate the importance of that capacity in our thinking. Moreover, we may fail to recognize the underlying sources of value associated with various capacities that are the true drivers of well-being. As Campbell and Stramondo write about certain activities that are prevented by various disabilities: "If we ask *why* such activities are good for a person, we are led to more general features: it is pleasurable; it is an engagement with beauty or an appreciation of human excellence; it strengths the quality of one's relationship; it is an achievement. These features are multiply realizable, and most disabilities only cut off certain avenues for achieving such goods" (2017, p. 157).

As such, it seems likely that armchair assumptions that the welfare of genetically engineered animals is "diminished" are likely to be vulnerable to similar mistakes as armchair assessments about the well-being of people under various conditions. Our intuitions in both cases can be seriously biased by our imaging how we would feel *immediately after* losing one of our own capacities. Just as we should take seriously the testimony of disability advocates that blind humans are capable of living as rich and emotionally rewarding lives as sighted humans, we should also recognize that there is no good reason to assume, prior to empirical evidence, that blind chickens, or dehorned cattle, or short-beaked chickens, will have lower well-being than other animals. The point here is not, of course, that genetic modifications that eliminate capacities *cannot* diminish animals' welfare, but only that we should not assume so in the absence of empirical evidence based on current best practices in the field of animal welfare.

A related argument suggests that we harm genetically modified animals not by diminishing their welfare, but rather by impairing what is *good for* them in other ways. One of the most influential accounts along these lines is the notion of integrity developed by Bovenkerk et al. (2001). They develop the notion of integrity as the

wholeness or intactness of animals, and suggest that diminishing integrity can harm animals even if welfare is improved. Similarly, Ortiz (2004) suggests that impairing an animal's dignity by interfering with the functions a member of the species can normally perform would nevertheless diminish an animal's "own good."

We believe these accounts are mistaken in suggesting that what is good for animals extends beyond the subjective experiences of the animals. If we claim that the goodness or badness of animals' lives are independent of their experiences, then we would be forced to conclude that there can be cases where animals have lives with a net balance of positive experiences that nevertheless are not worth living, in virtue of not conforming to our notions of integrity. But then consider a hypothetical case where we must choose between bringing into existence one of two animals: one animal genetically modified to lack some capacity but which has a life that overall has a net positive welfare,the other an animal that has not been genetically modified but has a life of net negative welfare. Neither Bovenkerk et al. nor Ortiz endorse the idea that integrity *always* trumps welfare in our moral equations, but given that they assign it some weight, it follows that there are some cases where they would have to recommend bringing into existence the animal with a net negative welfare over an animal with a positive welfare and diminished integrity. This, we believe, is an unpalatable result.[6]

These problems with appeals to integrity and dignity result from the fact that these notions conflict with what is called the Resonance Constraint in the human well-being literature, which suggests that what is good for an individual must in some way resonate with that individual. As Peter Railton wrote: "what is intrinsically valuable for a person must have a connection with what he would find in some degree compelling or attractive, at least if he were rational and aware. It would be an intolerably alienated conception of someone's good to imagine that it might fail in any such way to engage him" (1986, p. 9). An emphasis on integrity is an emphasis on a quality that in no way engages the lived experience of animals. As such, we reject the idea that what is *good for* particular agricultural animals can diverge from their welfare.

Some might argue that since Railton included the proviso "… at least if he were rational and aware," the Resonance Constraint does not in fact speak against the integrity or dignity views, since for all we know a fully "rational and aware" animal might value those qualities. But this is to stretch the proviso far beyond what was intended, to a place that would render the constraint practically meaningless. Imagine what it would mean to claim that "if my pig was fully rational and aware, he would recognize that integrity is in fact good for him." This would not be like a case of a person looking back at her 20-year old self, recognizing certain mistaken beliefs and saying "I should have pursued a career in music, since those experiences are what I truly find valuable." Rather, it would mean imagining the pig possessing

[6] As one of our reviewers notes, integrity might function in a different way, serving as a "tiebreaker" in cases of comparable welfare but never overriding considerations of welfare. This is an interesting idea, but Bovenkerk et al. and Ortiz both suggest that welfare can sometimes be overruled by considerations of integrity or dignity, respectively. Moreover, since we are specifically considering cases where, by hypothesis, the welfare of animals is improved in virtue of the modification, this suggestion doesn't cause any problems for our arguments.

cognitively sophisticated concepts like integrity or dignity, concepts that not only are not present in any actual pigs, but that appear to be completely removed from the kinds of cognitive capacities we associate with pigs. If the Resonance Constraint was stretched that far, it would lose all meaning, since we would then have to imagine it including concepts that are completely alien to the human species as possible determinants of what is truly good for us.

Finally, consider the claim that while genetic modifications may improve the welfare of individual animals, they nevertheless constitute violations of "species integrity" or an abstract notion of the dignity of the kind of animal. Bernard Rollin is the scholar responsible for bringing the idea of *telos* into debates about animal welfare. The *telos* of an animal refers to "the set of needs and interests which are genetically based and environmentally expressed, and which collectively constitute or define the 'form of life' or way of living exhibited by that animal, and whose fulfillment or thwarting matter to the animal" (1998, p. 162). Respecting an animal's *telos* involves allowing it to engage in the set of behaviors that express its form of life.

It might initially seem as though genetically modifying an animal would be failing to respect the animals' *telos*. Placing moral weight on species integrity seems misguided, however. For as Rollin himself points out, when you change the genetics of the animal you are changing that animals' *telos*, and as such you are not failing to respect the animals' *telos* if you provide it with an environment that fits its altered genetic dispositions. Moreover, placing so much weight on integrity is choosing to prioritize an abstract concept referring to a general set of tendencies. It is hard to see how this could ever be thought to outweigh the actual suffering of an individual animal. Finally, there is no true fixed set of behaviors or natural tendencies for a species that endures over time. General behavioral tendencies change over time and at any given time many members of the species are outliers. Eventually "common" behaviors for a species might disappear entirely as a result of natural selection. The idea that there is some "true essence" of a species that cannot be changed over time is empirically mistaken, and so it is hard to see why divergences from a central tendency should be seen as morally problematic when they are in fact a common feature of the biological world.[7]

The Central Problem: Comparative Disadvantages to Other Approaches

Though we have argued that using gene editing to improve welfare is preferable to the current status quo, this technique is nevertheless at a serious disadvantage to other possible alternatives, particularly when we consider the ethical challenges raised by a growing population and the effects of modern agriculture on the environment.

[7] Of course, there are features of the biological world that can be morally problematic, but the point here is that species seem to be valued precisely because they represent some natural feature of the world; mutations and divergences from the central tendency seem to have just as much claim to representing a natural feature of the world as do species.

Plant-based alternatives to meat, dairy, and eggs have been impressively successful in the marketplace in recent years. In particular, plant-based dairy products have made serious headway in the total purchasing of milk; over a 5-year period between 2011 and 2015, the total milk market shrunk by $1 billion in the United States while sales of almond milk increased by 250% (Neilsen 2016). A massive societal shift towards a primarily plant-based diet would require less land usage, result in dramatically less greenhouse gas emissions, eliminate other environmental problems associated with intensive confinement operations, be more healthy than the typical American diet (and comparably healthy to diets that use small amounts of animal products), and eliminate the potential suffering of billions of animals (McMicheal et al. 2007). Considering that current realistic uses of genetic engineering on animals would address these problems only, at best, in a piecemeal fashion, and seemingly would not overcome the land and resource usage issues, they seem to be at a clear disadvantage when compared to shifting to a plant-based diet.[8]

Another alternative that has recently been gaining momentum is the creation of lab-grown meat, referred to as "clean meat" by its advocates. Though many technical hurdles remain, including the ability to scaffold the grown tissue in a manner that mimics the texture of traditional meat, this technique, if successful, could all but eliminate the use of animals, dramatically reduce the usage of land and resources, and decrease much of the pollution associated with animal agriculture (Datar and Betti 2010). Unlike plant-based approaches, it is currently unclear if lab-grown meat will be successful in overcoming technical challenges, and it might also trigger similar intuitive negative reactions to genetic modification. On the other hand, the last several years have seen a rapid succession of advancements and growing investor interest in the field.

As noted above, though deontological animal rights theorists might concede that welfare enhancement is preferable to the status quo, few animal rights advocates would ever accept gene editing for welfare as an adequate end-point for social change related to animal agriculture. Raising animals for food would still be impermissible on such views. In contrast to this, a massive societal shift towards plant-based foods or in vitro meat products could presumably lead to tolerable conditions for deontological accounts of our duties to animals. This is a further advantage of these alternatives.[9]

[8] Another suggestion is that we could simply choose to move away from current intensive confinement conditions and back towards models where livestock are able to graze freely for most of their lives. While this could work in particular contexts and on a smaller scale, it does not seem to be a plausible option if the global population continues to grow as expected and meat consumption trends continue. As such, this could be considered part of a solution, but most likely would need to be combined with a general shift toward plant-based diets or some other type of solution. And, by itself, this would not seem to address the fact that even organic and small scale farming operations raise challenges for the environment and land-use decisions.

[9] Some take this claim further and suggest that improving animal welfare will actually impede the ultimate social change needed to reach a morally tolerable state by putting a band-aid over the problem and appeasing public concerns. These claims are always highly speculative, and one might alternatively claim that getting the public to think more about welfare will in fact lead to even further changes down

When compared with a shift towards plant-based diets or to in vitro meat, genetic engineering could be seen as the least attractive choice. Nevertheless, there are reasons to believe that this approach should still be pursued and, moreover, that it is possible that gene editing could be the approach that actually ends up having the most influence on the future of food despite the ethical advantages of these other options.

A Path Forward

Though gene editing to improve welfare is not the optimal solution, there are nevertheless reasons to think that gene editing of livestock will continue to move forward. It will therefore be important to advocate that animal welfare improvements are included as a central part of gene-editing research.

The first reason that gene editing for welfare is likely to stay relevant is that some agricultural research centers have already decided that gene editing represents the future of agriculture and is required for agriculture to address pressing challenges related to population growth and the environment. For example, Washington State University has committed to hiring a group of new faculty for a Functional Genomics Initiative that is premised on the assumption that "the science of genome editing will influence society on an unprecedented scale over the next decade: curing genetic diseases, improving agricultural production, and revolutionizing the models available for biomedical and life sciences research" (WSU 2016). One of the stated goals of the program is to "implement this technology in large animal/livestock species" in order to "solve critical problems to improve public health worldwide by controlling disease and feeding a global population that will reach ~ 9.5 billion by 2050."

Given that gene editing of livestock with the explicit goals of creating benefits for humans will be taking place, it will be important to ensure that these gene editing efforts are also taking animal welfare under consideration. Bernard Rollin offered a useful principle in this regard called the Principle of the Conservation of Welfare. He proposed that, "any animals that are genetically engineered for human use should be no worse off, in terms of suffering, after the new traits are introduced into the genome than the parent stock was prior to the insertion of the new genetic material" (Rollin 1995, p. 169).[10]

Since industries using gene editing will be competing against other technologies that cause significantly less suffering (plant based and in vitro alternatives), it is likely that they will need to be especially mindful of animal welfare. In recent years, large companies such as Wal-Mart, Target, Aldi, Kroger, and Starbucks have

Footnote 9 continued
the road. It's difficult to know how to evaluate such speculative claims and as such it seems highly dubious to ever use them to block concrete improvements in welfare.

[10] It is worth noting, as one of our reviewers pointed out, that Rollin's Principle of Conservation of Welfare is more restrictive than current policies and practices related to selective breeding. Hopefully, the moral controversy surrounding genetic modification can help ensure that new practices are held to higher standards.

committed to improved animal welfare standards in their supply chains. Aramark, TGIF, and Panera have adopted new welfare standards that require its suppliers to commit to slower growing chickens, which is a direct conflict between welfare and productivity. Much evidence suggests that consumers in developed countries are leaning more towards animal products that strike a balance between cost and welfare. Companies that ignore these trends and fail to include welfare in their plans will risk putting themselves at a serious disadvantage compared to other approaches.

As noted above, there are a number of low-hanging fruits already available or likely to be available in the near future that would allow gene-editing animal scientists to make significant welfare improvements. Many of these are consistent with the goals of industry: for instance, increasing disease resistance clearly is good for the bottom line as well as welfare and eliminating the need for painful procedures would allow workers to avoid unpleasant experiences. So there are a number of relatively easy opportunities to make significant welfare improvements via targeting specific welfare concerns and a potential for more dramatic possibilities in the future.

The second reason to believe that gene editing for welfare will remain relevant is that gene editing is already used extensively in animal research to artificially create animal models for human diseases and to understand the central nervous system. Though the efficacy of such uses is hotly debated, it nevertheless is clear that such usage is going to continue in the near future. Moreover, the ethical case against the use of animals in research is weaker than the case against eating animals that come from modern farming. In the latter case, serious harms occur to far more animals, and it is unclear that there is a significant benefit to humans compared to alternatives, let alone benefits that outweigh the harms that are caused. In the case of research, however, there is at least a strong, evidence-based consequentialist argument to be made that that the health benefits that result from some forms of invasive animal research outweigh the harms caused by that research.

But precisely because so much is already known about genetic engineering in the research context, there are opportunities to relatively quickly use gene editing to improve the welfare of laboratory animals. As mentioned above, John Wood at University College London has created a strain of mice that mimic humans who are born without the ability to feel pain. In particular, these humans and mice have increased endogenous opioids that act as painkillers throughout their lives and for reasons that are not entirely understood they fail to develop a tolerance for the opioids. One problem with using Wood's mice as a model for research, as noted above, is an objection frequently raised to the idea of using gene editing eliminate the capacity to suffer: in the absence of a suffering signal, the animals tend to cause serious self-harm. However, investigations are currently underway to see if gene editing could be used to produce mice that are not pain-free from birth, but who rather can be triggered to be pain free via the introduction of an inert bio-compound. It is thus easy to see how research on using gene editing to improve welfare could progress in the laboratory and later be translated to in agricultural settings.

And finally, it is worth noting that the primary theoretical advantages of alternative approaches could potentially also be partially mitigated through the employment of genetic technology. Genetic engineering has applications that could

in principle address environmental concerns as well as improve human nutrition. A prominent environmental concern in animal agriculture is the pollution caused by manure (Jongbloed and Lenis 1998). In pork production, phytate phosphorous is the most significant pollutant expelled in manure and contributes to eutrophication of freshwater sources. Pigs have been genetically modified to produce a salivary enzyme that allowed them to digest phytate phosphorous, rather than expel it in their manure (Golovan et al. 2001). This resulted in pigs not requiring phosphorous supplements and producing 75% less phosphorous in their manure compared to non-genetically modified pigs. Development on this project stopped, but it did demonstrate that there are at least potential applications of genetic technologies that might mitigate some of the environmental concerns.

There are also opportunities to use genetic modification to improve human nutrition. For example, dairy cows have been genetically modified to have additional copies of the genes encoding the nutritionally valuable β- and κ-casein proteins, resulting in the production of milk with increased β- and doubled κ-casein protein content (Smolenski et al. 2003). There is also evidence that genetic modification can be used in dairy cows and goats to reduce or eliminate production of the protein β-lactoglobulin, a common allergen, in milk (Jabed et al. 2012; Cui et al. 2015). Pigs have been genetically modified to contain a gene that allows them to synthesize poly-unsaturated fatty acids (Saeki et al. 2004). These fats have been shown to promote health benefits such as decreased risk of coronary disease (Simopoulos 1999). Pigs have also been genetically modified to produce omega-3 fatty acids, which are essential to human nutrition but are not currently present in pork (Lai et al. 2006). Taken together, these examples show that improving the nutritional quality of animal products and byproducts is possible through use of genetic modification. While human health may be benefited in some ways by adopting a plant-based diet, genetic modification of animals provides other ways in which nutrition can be improved.

Conclusion

So, though there are some disadvantages to using genetic modification to improve welfare, it nevertheless remains a viable option for dramatically reducing suffering in the future. Moreover, given that gene-editing research is already taking place, it will be important for those who care about welfare to advocate for something akin to Rollin's Principle for the Conservation of Welfare to be a central consideration of any future gene-editing projects involving farm animals. As such, given the uncertainty surrounding the potential development of in vitro meat and the adoption of plant-based diets, genetic modification remains an important alternative to pursue for the sake of improved animal well-being. It is often not people's first choice when they are asked to imagine the ideal future of food, but it may turn out to be the best choice.

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